

Quarkonia production from RHIC

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Iowa State University

2017 RHIC & AGS Annual Users' Meeting

Quarkonia in Heavy Ion collisions

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PHYSICS LETTERS B

9 October 1986

>2500 citations

J/ ψ SUPPRESSION BY QUARK-GLUON PLASMA FORMATION \star

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Received 17 July 1986

If high energy heavy ion collisions lead to the formation of a hot quark-gluon plasma, then colour screening prevents $c\bar{c}$ binding in the deconfined interior of the interaction region. To study this effect, the temperature dependence of the screening radius, as obtained from lattice QCD, is compared with the J/ψ radius calculated in charmonium models. The feasibility to detect this effect clearly in the dilepton mass spectrum is examined. It is concluded that J/ψ suppression in nuclear collisions should provide an unambiguous signature of quark-gluon plasma formation.

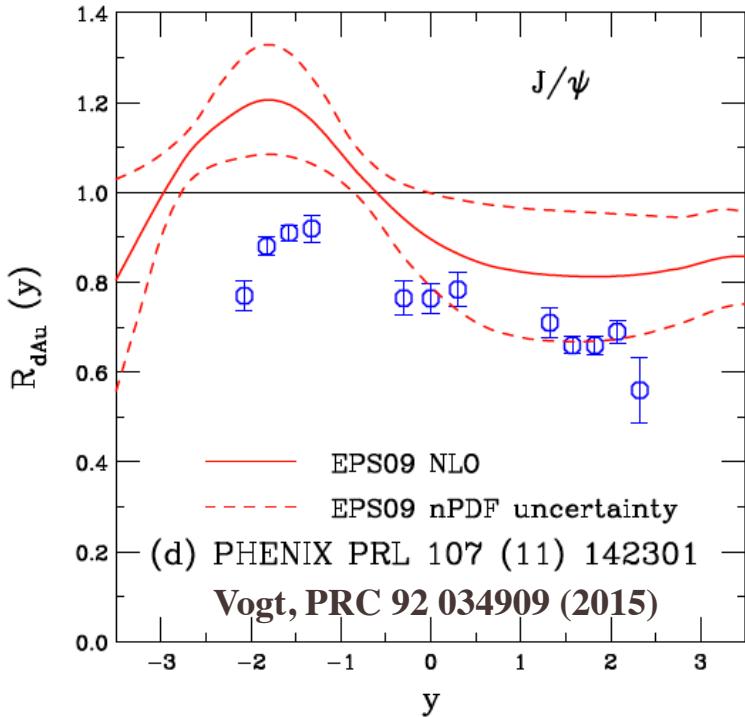
“unambiguous signature of QGP formation”

Quarkonia in HI collisions

PDF Modifications

HYSICS LETTERS B

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ON PLASMA FORMATION ★

ar Science, Massachusetts Institute of Technology,

Elefeld, Fed. Rep. Germany
Laboratory, Upton, NY 11973, USA

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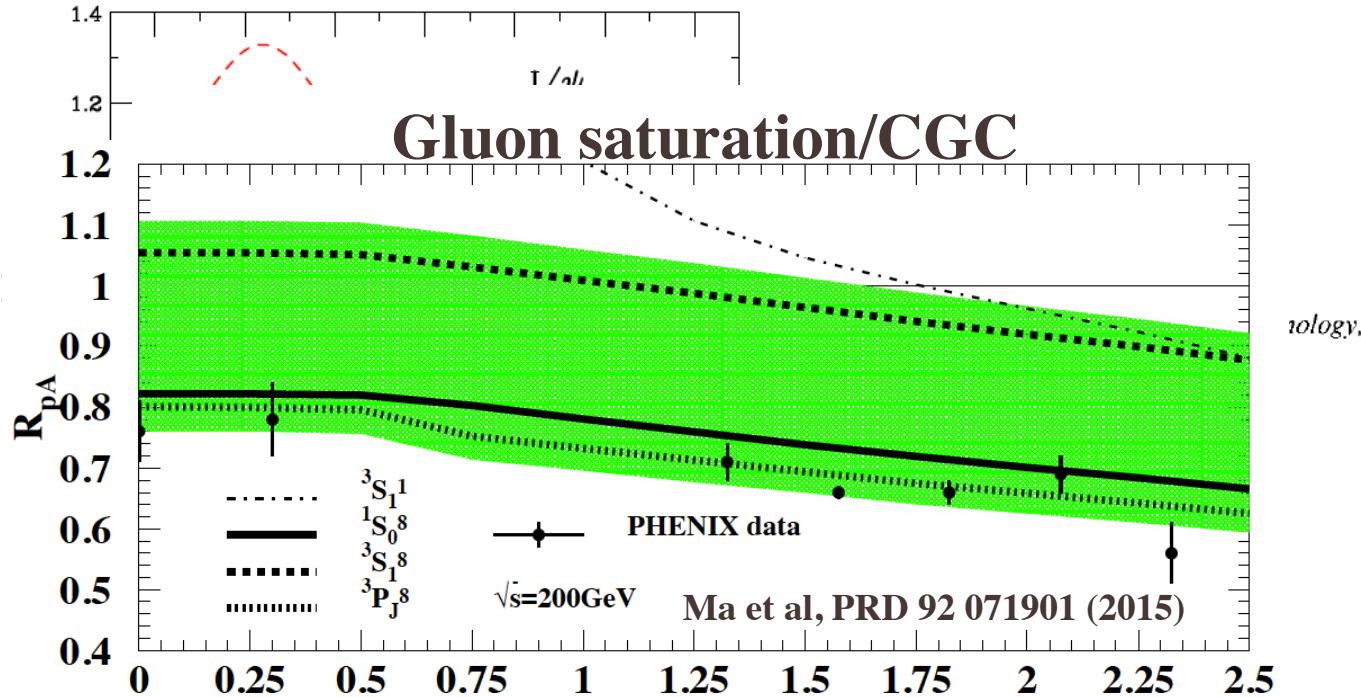
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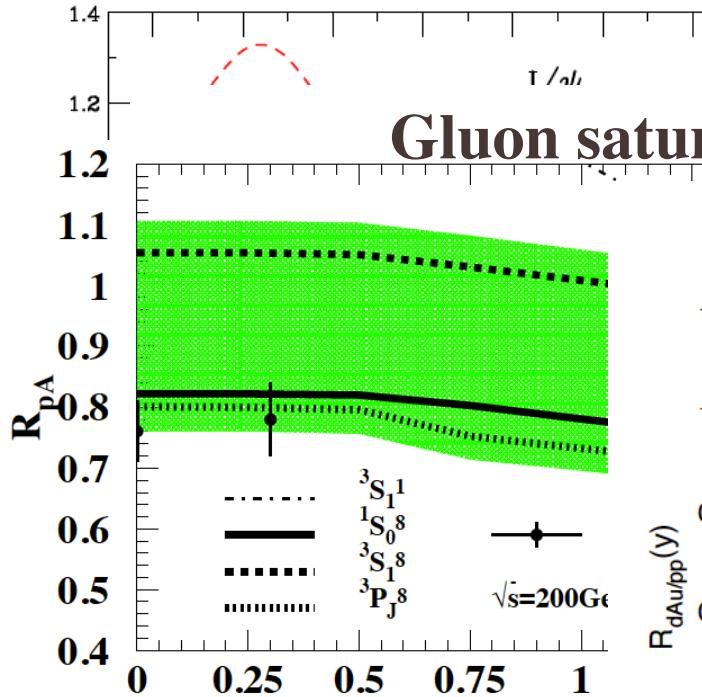


If high energy heavy ion collisions lead to the formation of a hot quark-gluon plasma, then colour screening prevents $c\bar{c}$ binding in the deconfined interior of the interaction region. To study this effect, the temperature dependence of the screening radius, as obtained from lattice QCD, is compared with the J/ψ radius calculated in charmonium models. The feasibility to detect this effect clearly in the dilepton mass spectrum is examined. It is concluded that J/ψ suppression in nuclear collisions should provide an unambiguous signature of quark-gluon plasma formation.

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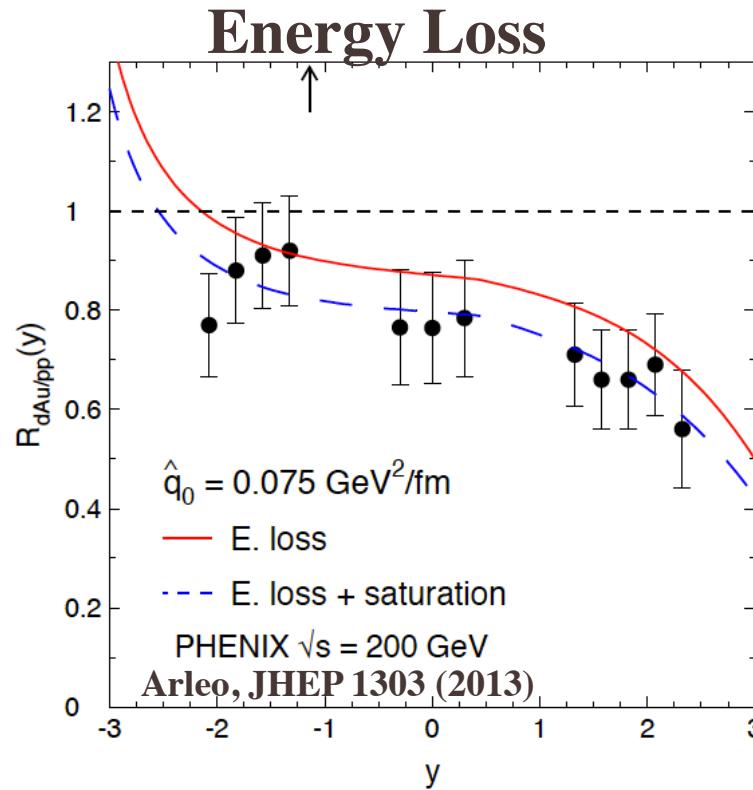


If high energy heavy ion collisions in the deconfined interior of the interaction obtained from lattice QCD, is compared clearly in the dilepton mass spectrum unambiguous signature of quark-gluon

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Gluon saturation/CGC

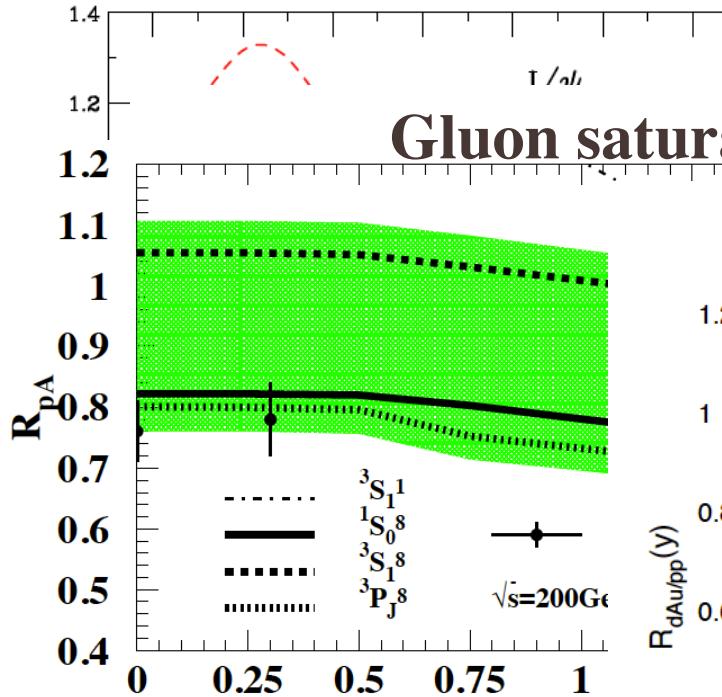


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“unambiguous signature of QGP formation”

Quarkonia in HI collisions

PDF Modifications

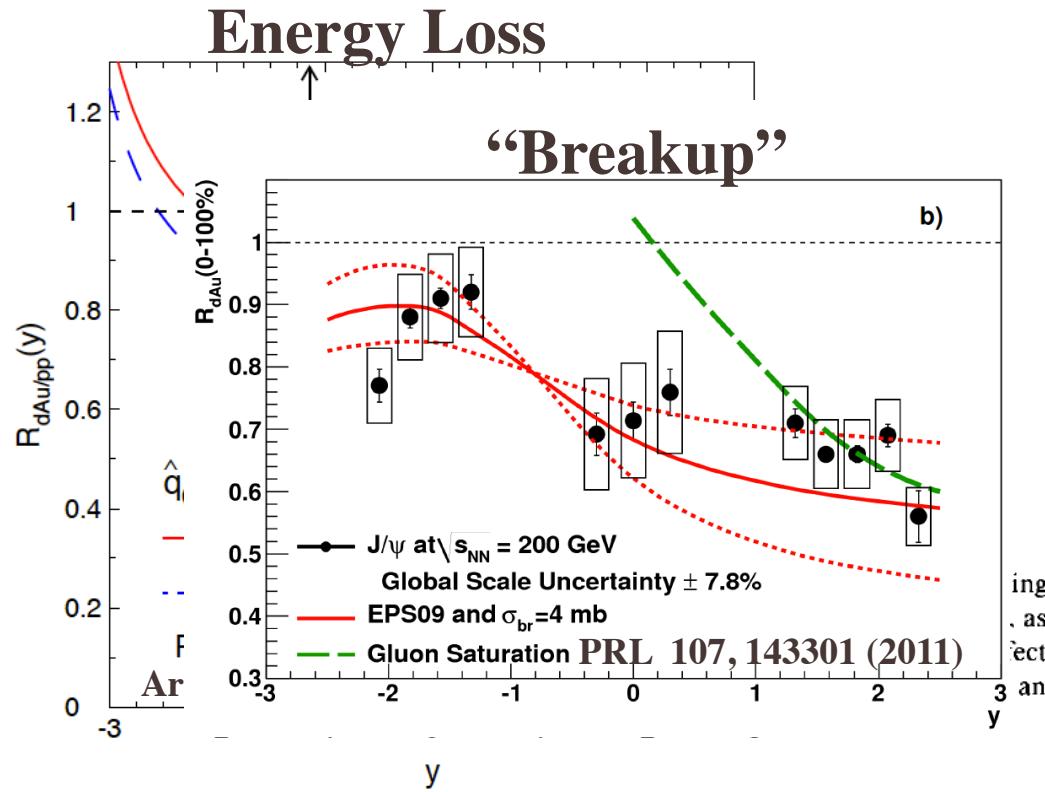


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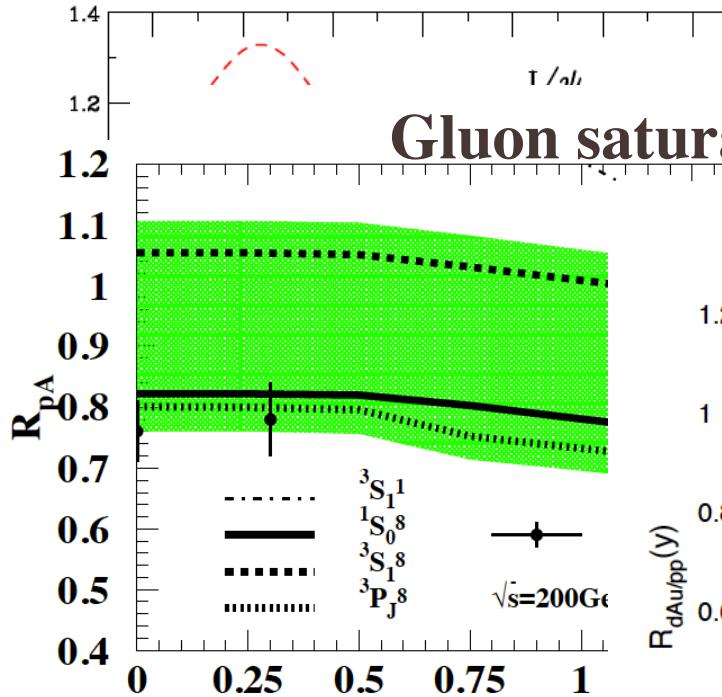
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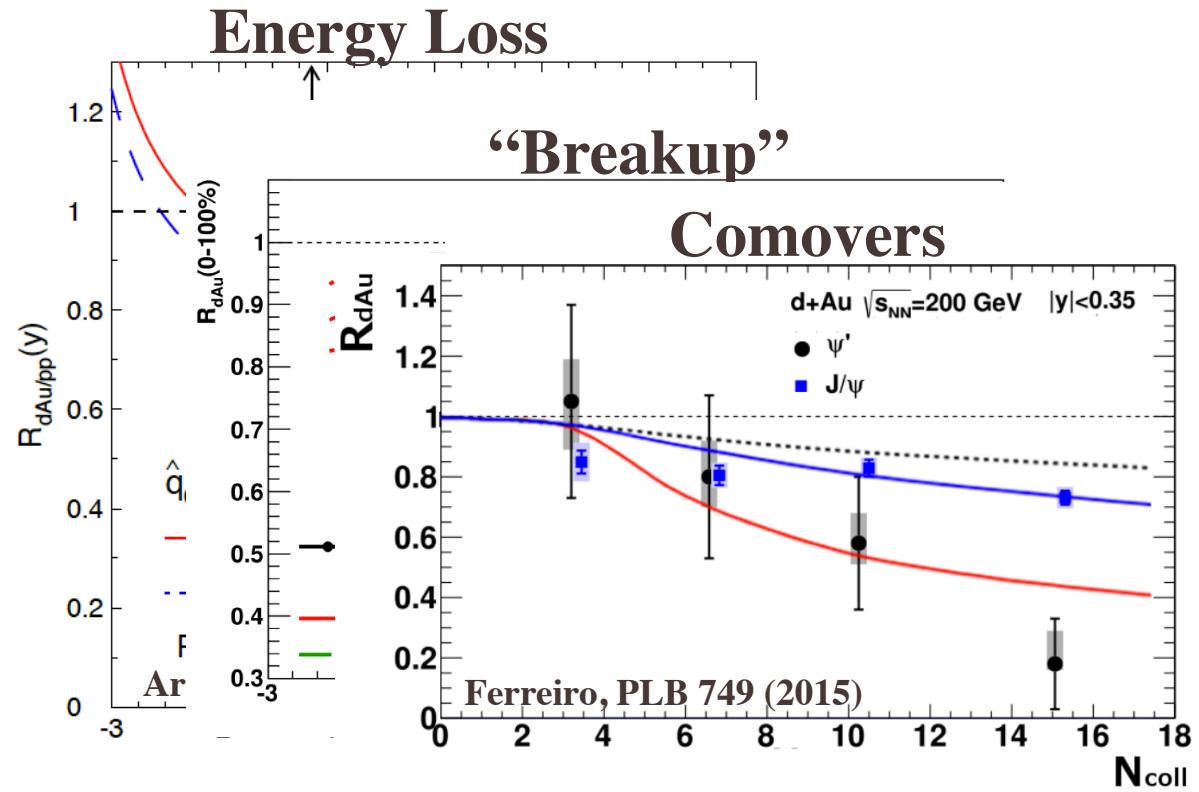


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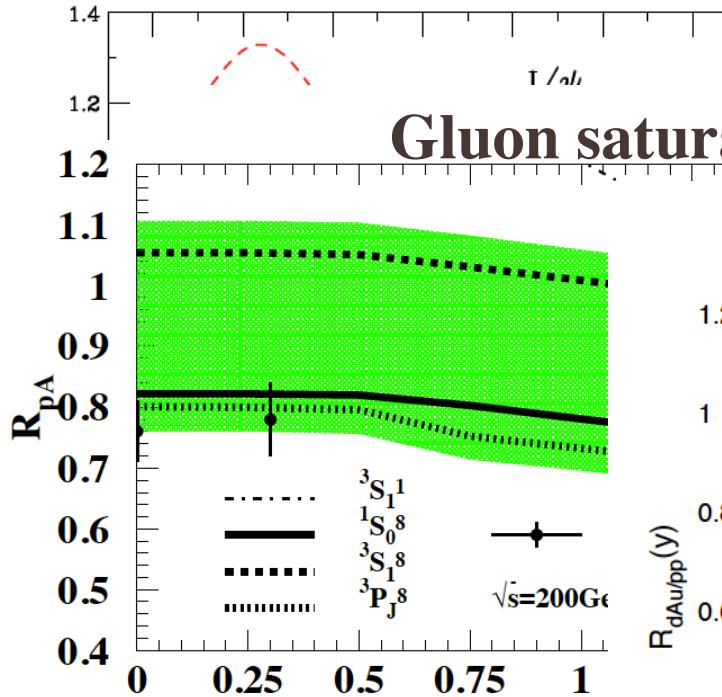
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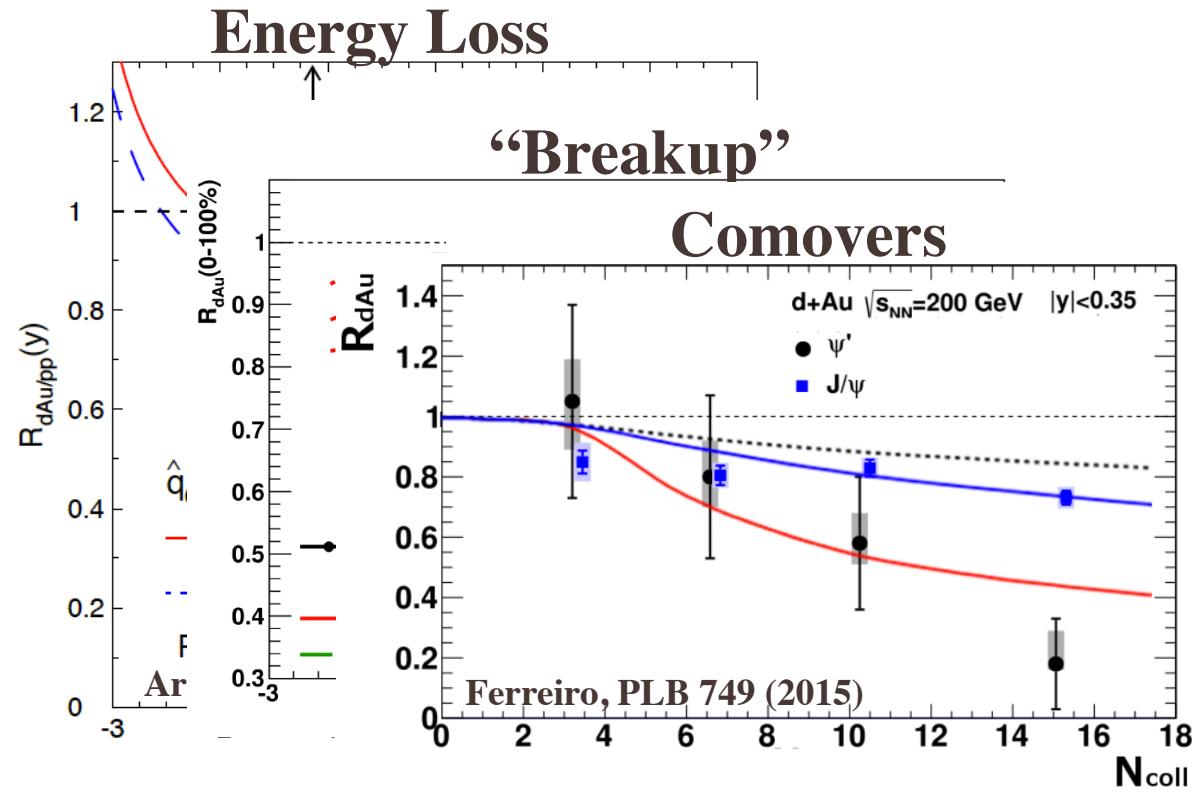


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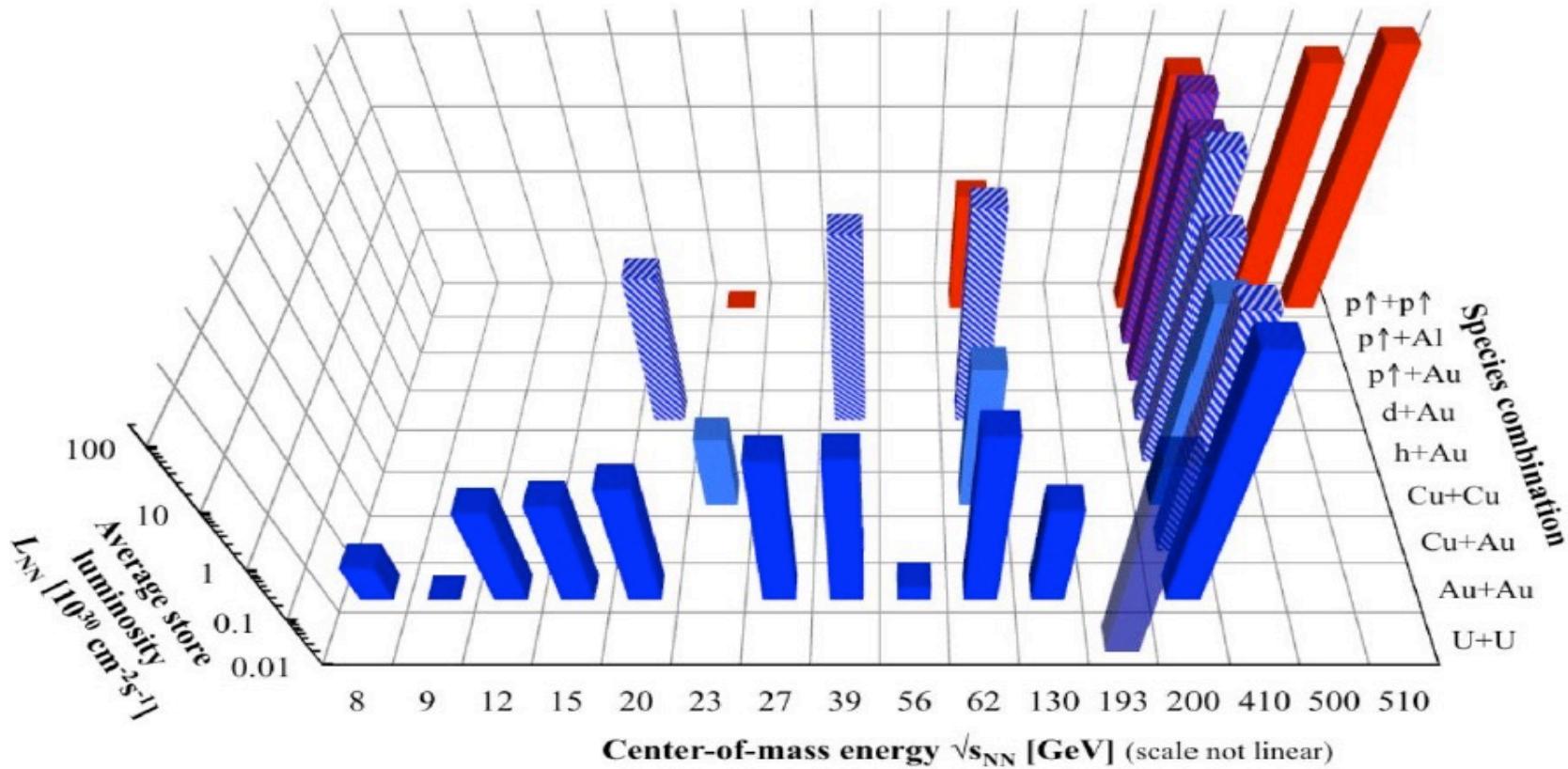
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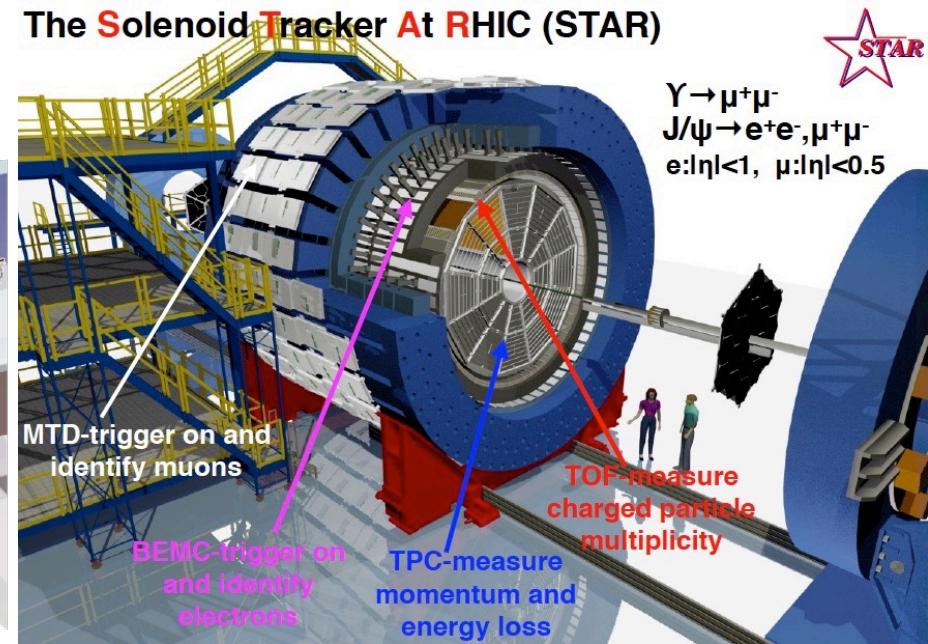
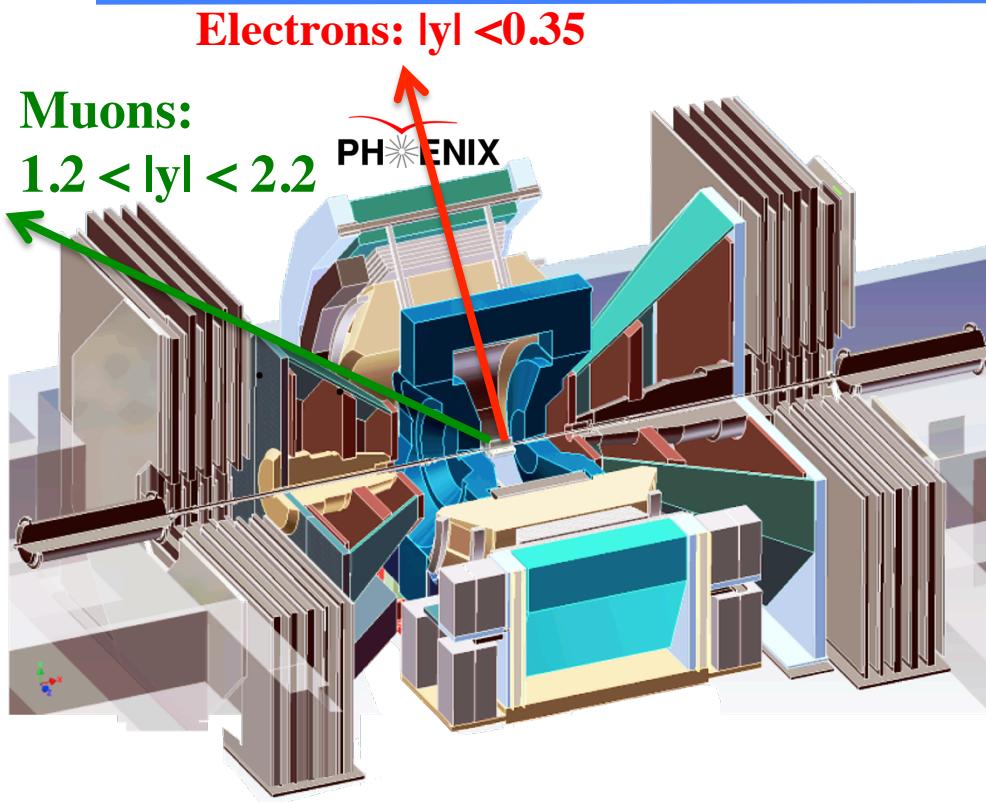
RHIC is unique

From Run1 to Run16



RHIC knobs: **System size, Collision energy**

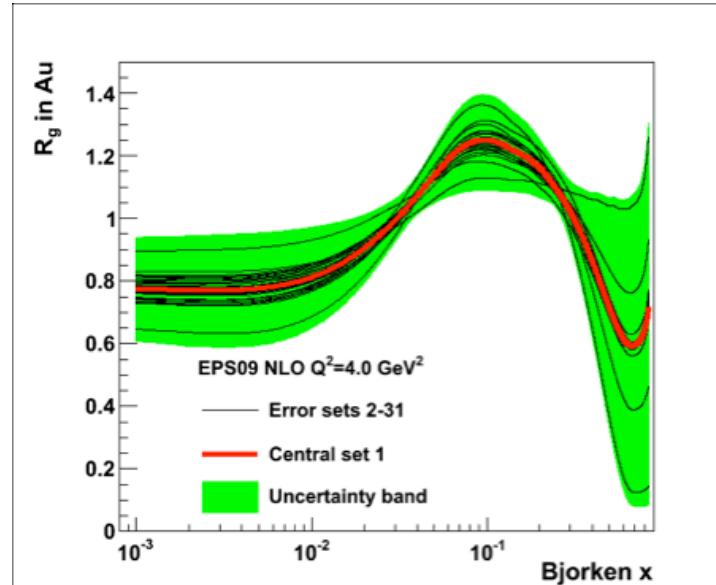
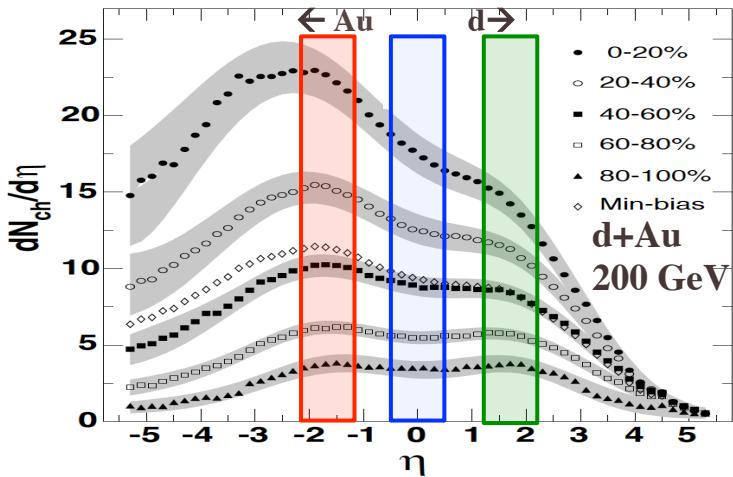
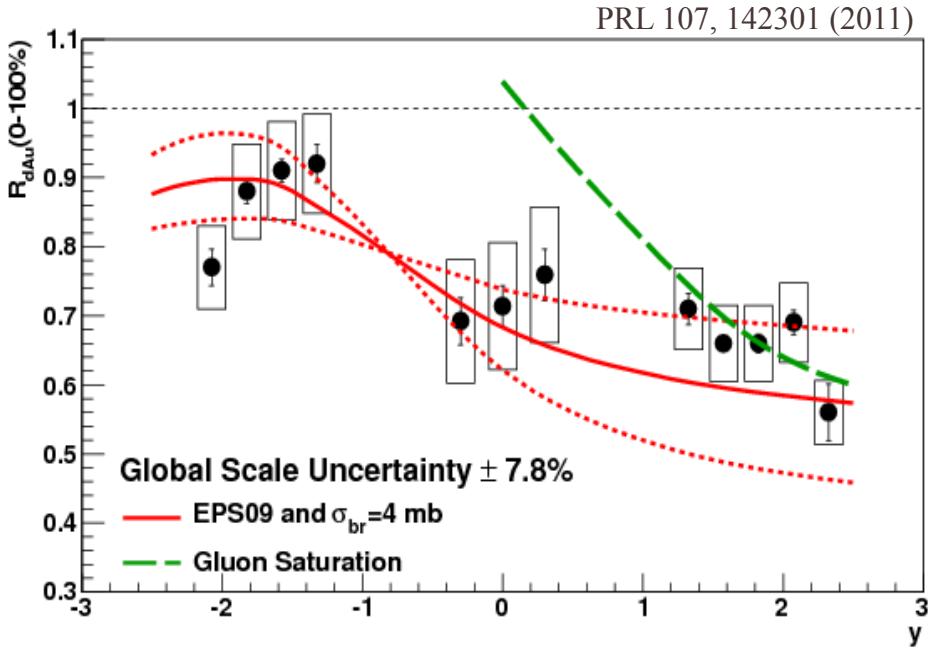
PHENIX and STAR Detectors



PHENIX/STAR knobs: **Quarkonia species, Momentum, Rapidity**

Small systems

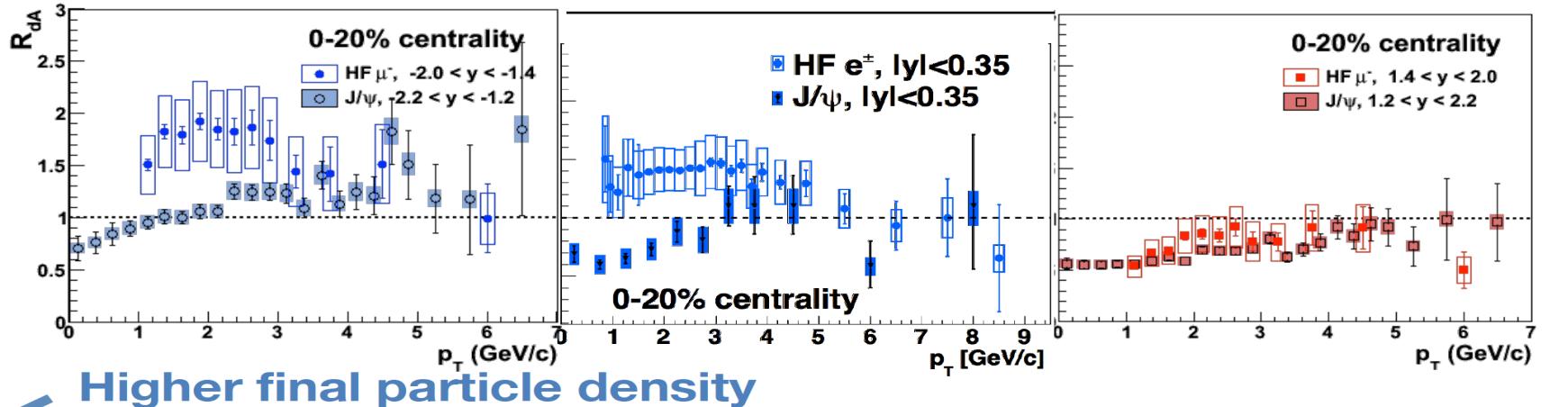
J/ψ suppression in $d+Au$



- Suppression of J/ψ compared to $p+p$ collisions at the entire rapidity region
 - Not expected from PDF modification
→ something beyond the PDF modification
 - Model including 4 mb of breakup shows a good agreement with the data

Sanity check: Open vs closed charm

arXiv:1310.1005, Phys.Rev.Lett. 109 (2012) 24, 242301, Phys.Rev. C87 (2013) 3, 034904



← Higher final particle density →

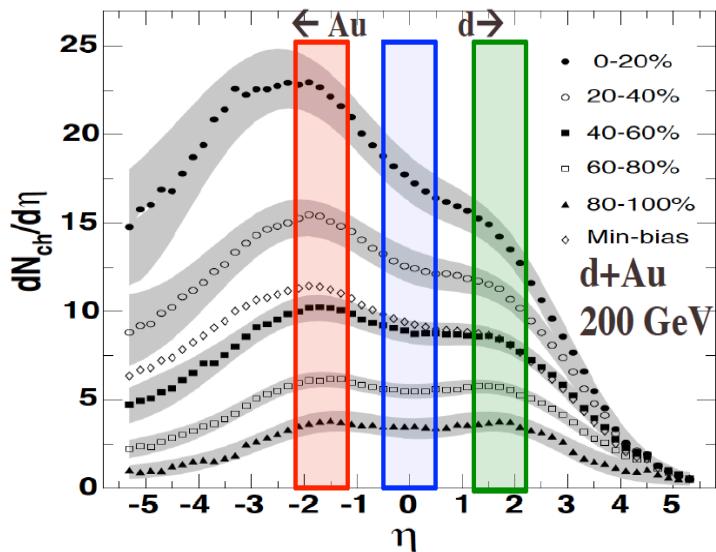
Probing lower-x gluons in Au

Caveat: Different kinematics

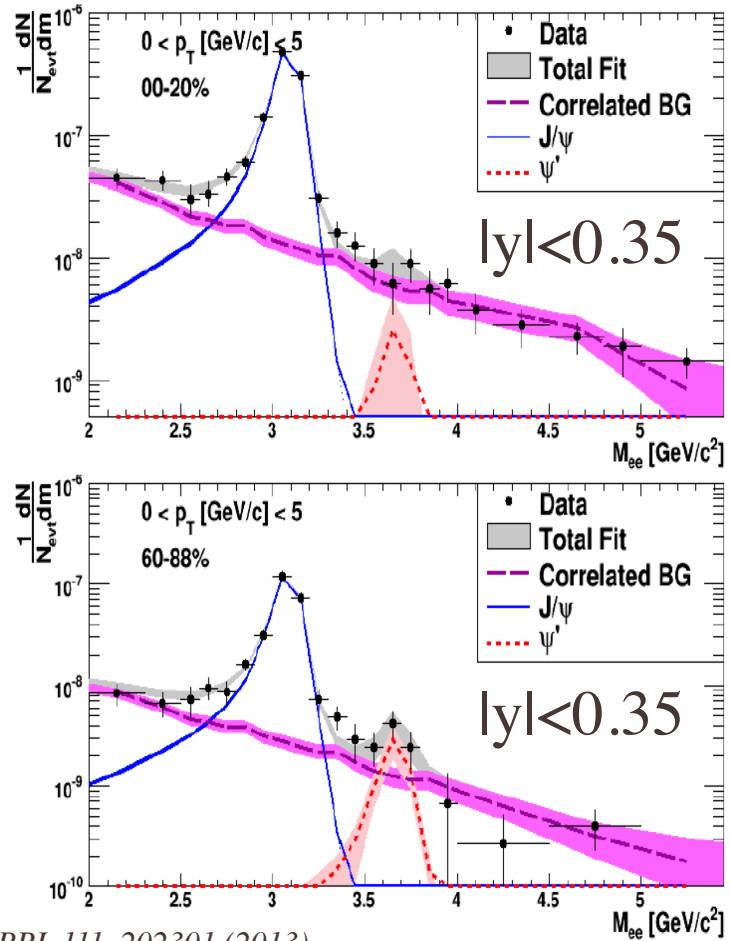
Same gluon-shadowing, energy loss and Cronin.
A significant J/ ψ break-up at backward rapidity.

..But.. HF enhancement at backward and mid rapidity.

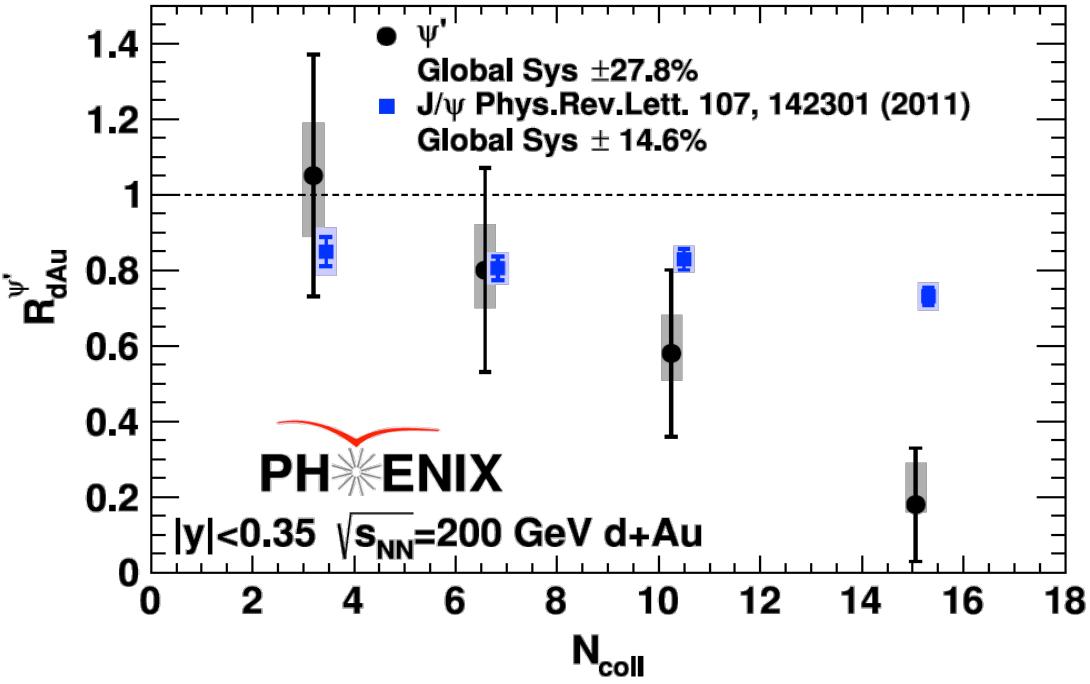
➤ Final state interaction? Comovers?



$\psi' R_{dAu}$

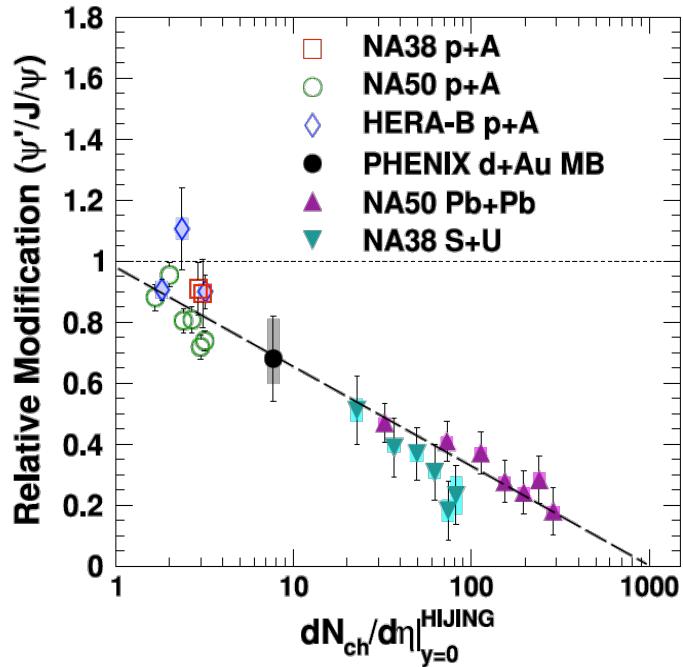
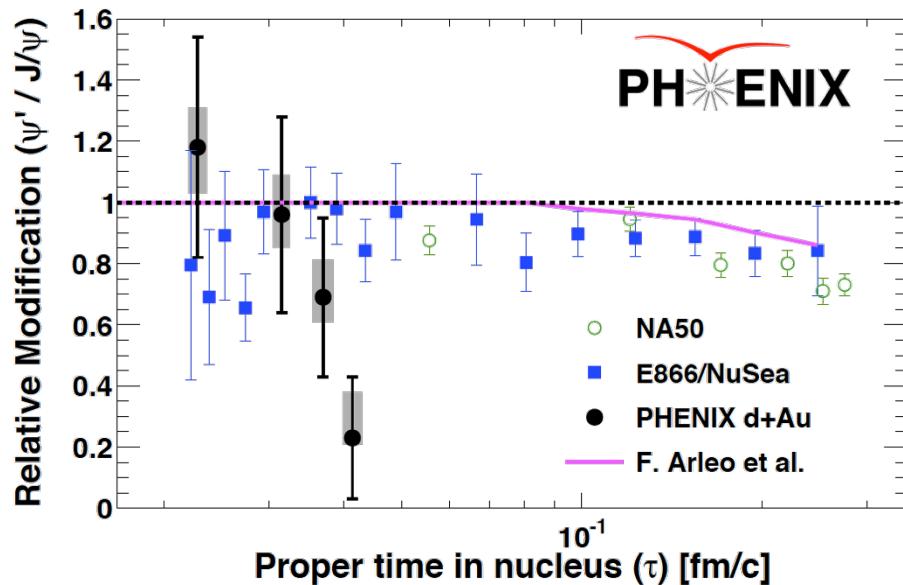


PRL 111, 202301 (2013)



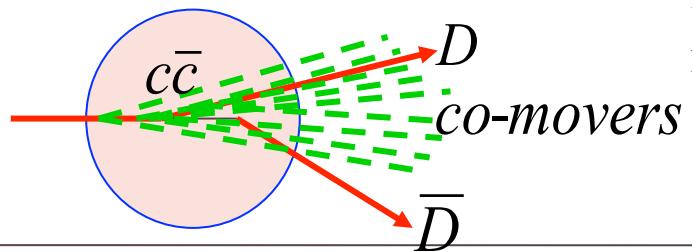
Strong suppression of ψ' with increasing N_{coll} at the mid-rapidity.

Modification inside/outside nucleus?



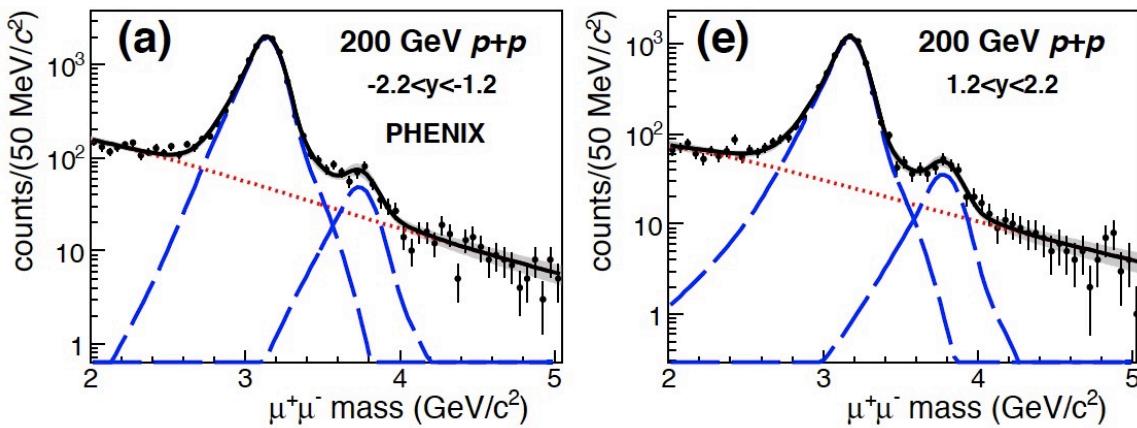
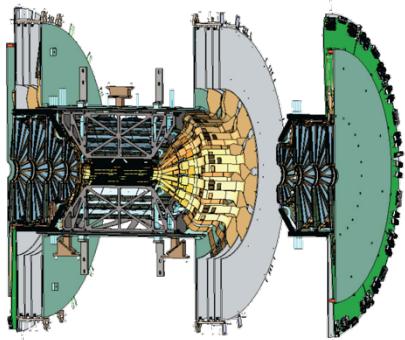
Phys. Rev. Lett. 111, 202301 (2013)

- ❖ Larger relative modification of $\psi(2S)$ than the estimation of breakup in nucleus
→ at RHIC, formation time of J/ψ (~ 0.15 fm) is longer than the proper time in nucleus (~ 0.05 fm)



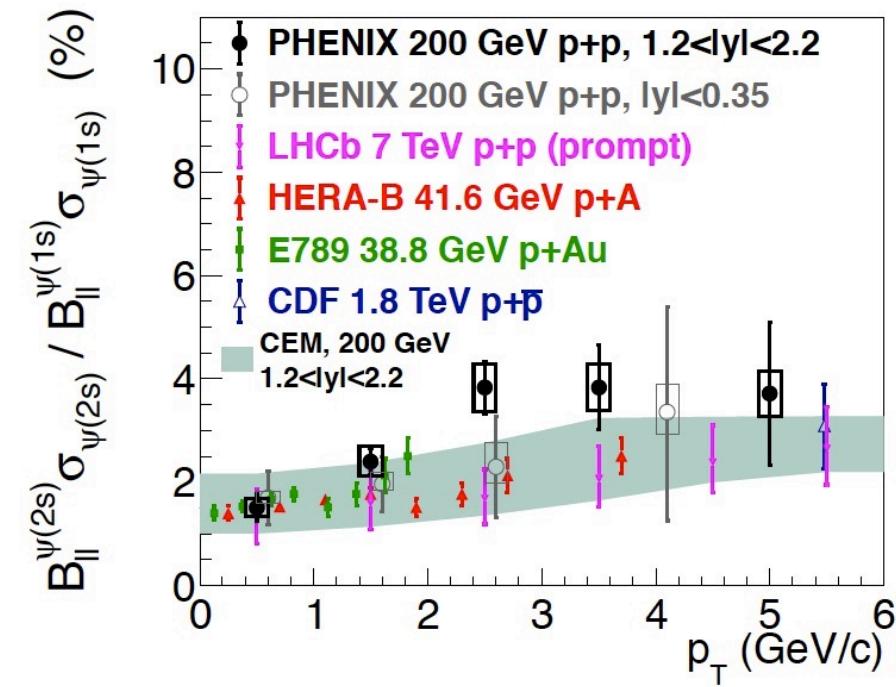
Breakup of quarkonia due to interaction with nucleus? co-movers? or medium?

$\Psi(2S)$ at forward rapidity with FVTX

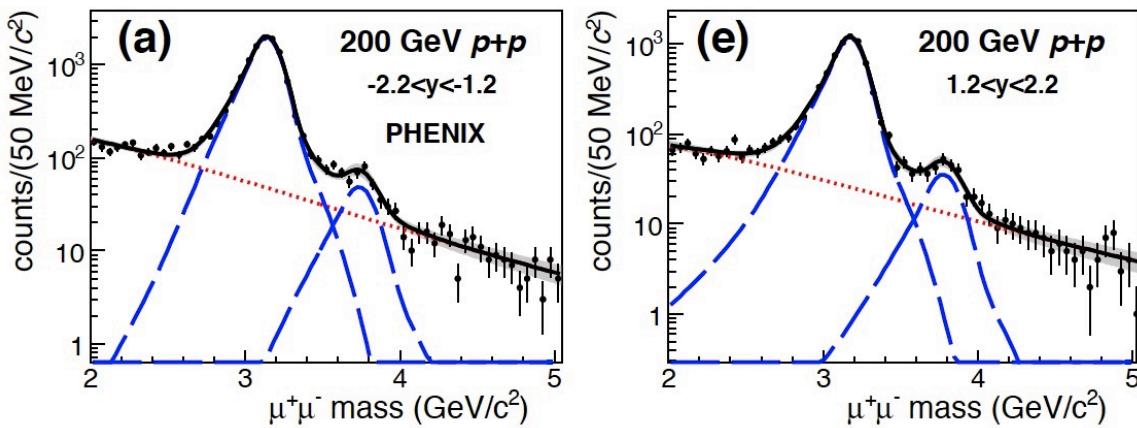
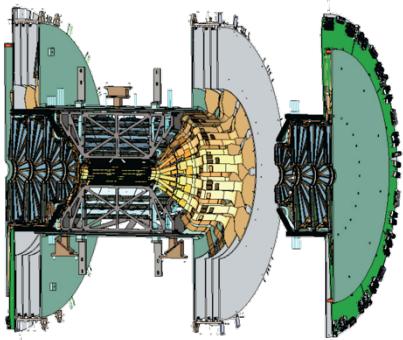


VTX/FVTX detector at PHENIX added new capabilities.

Resolved $\Psi(2S)$ state at forward/backward rapidity.



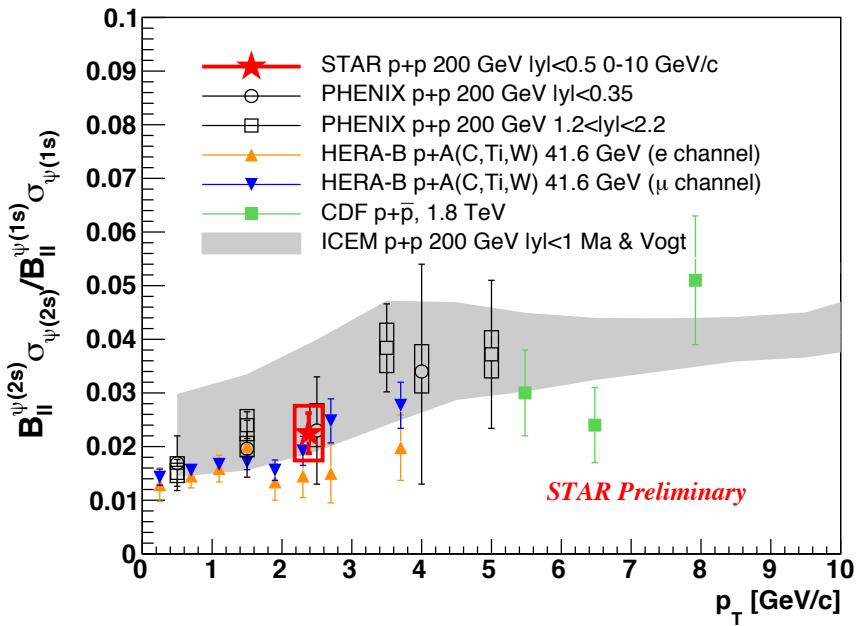
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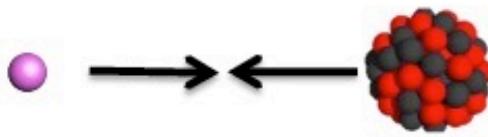
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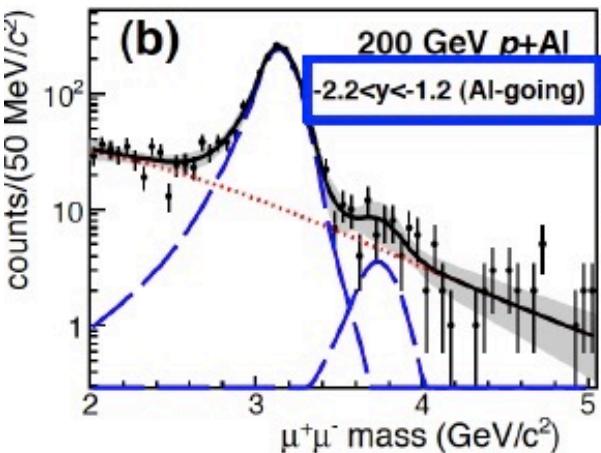
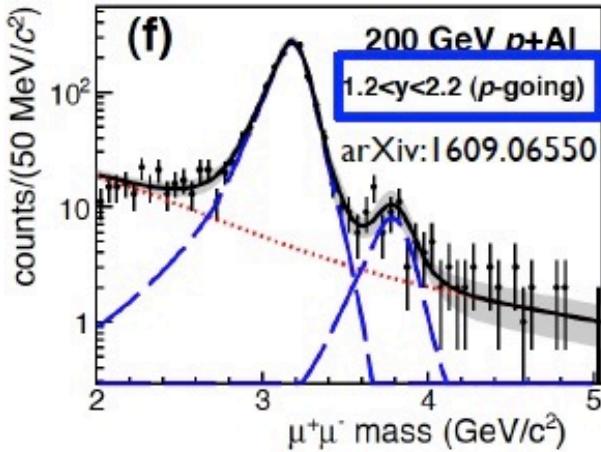
Recent STAR measurement at midrapidity.



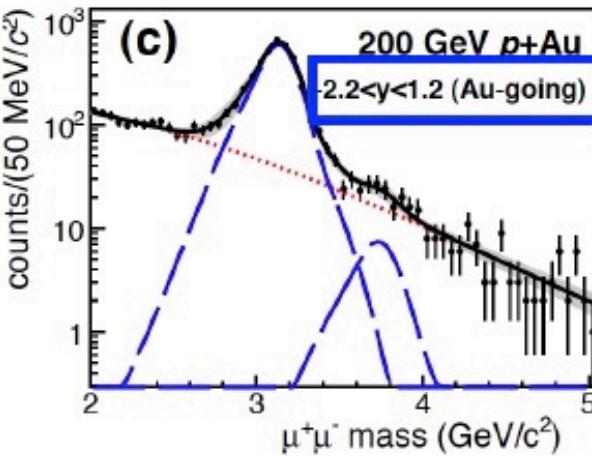
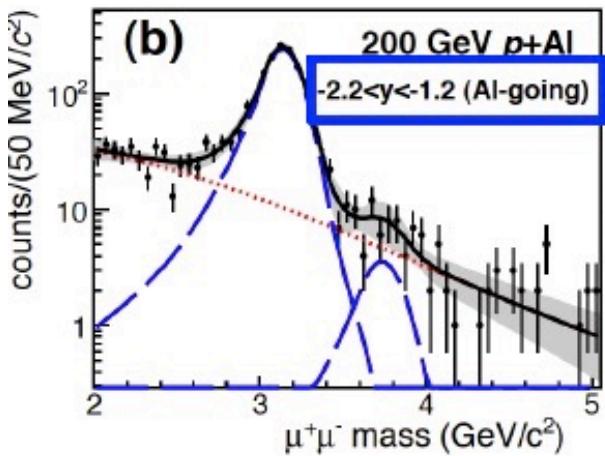
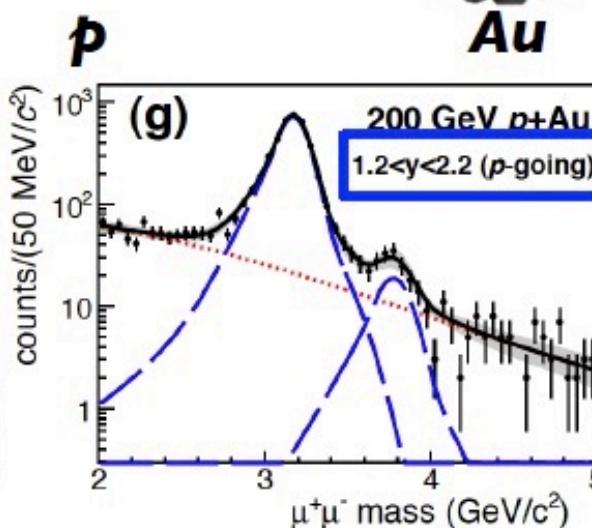
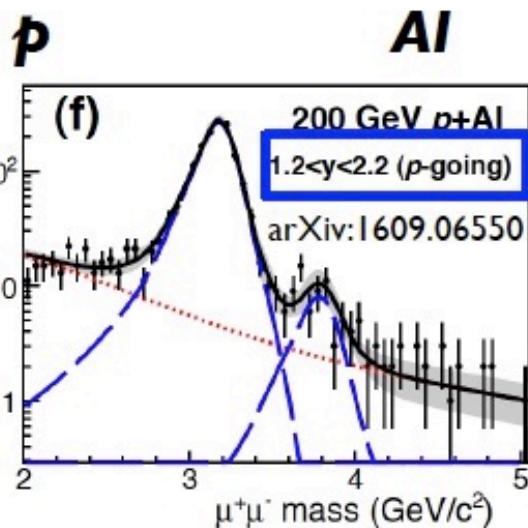
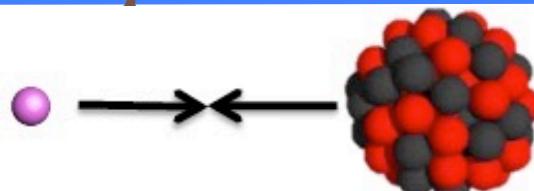
$\Psi(2S)$ at $p+A$ collisions



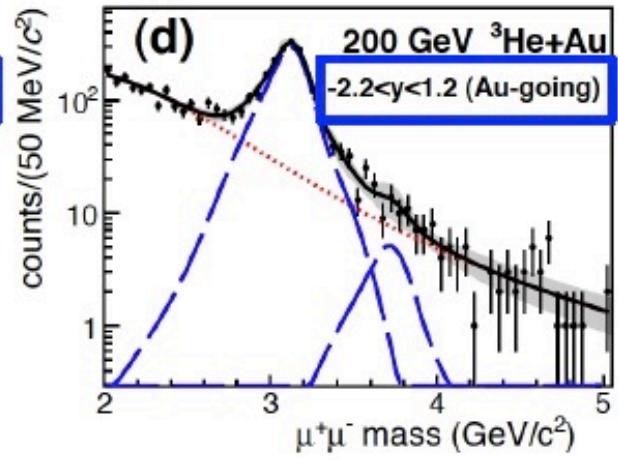
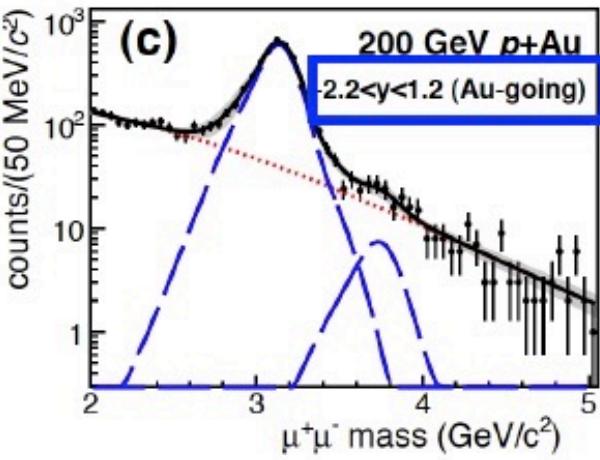
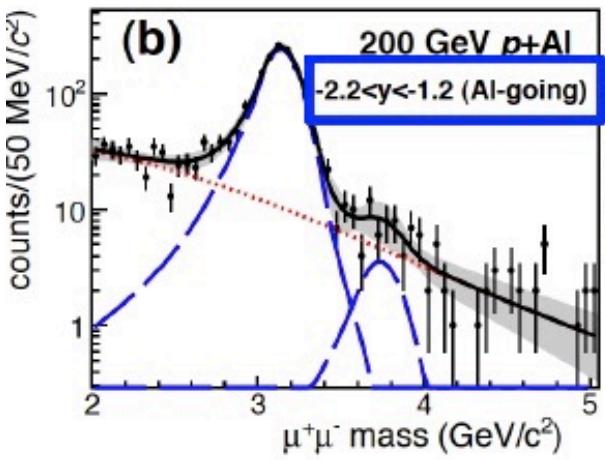
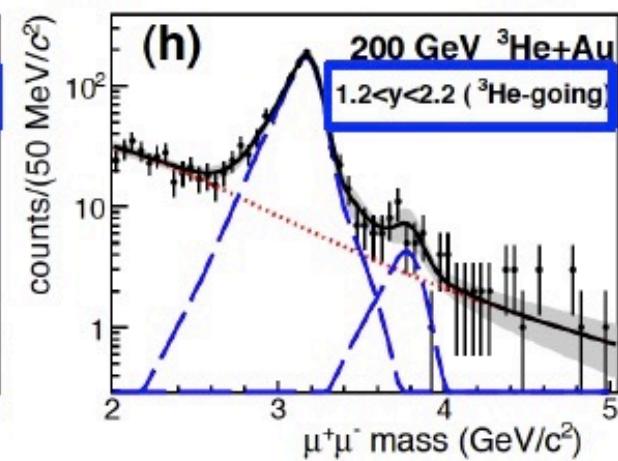
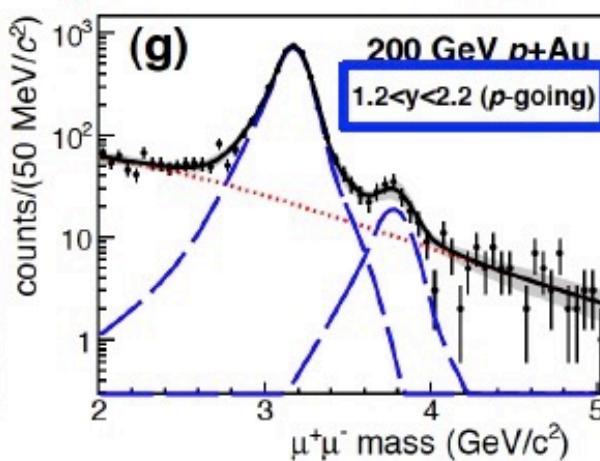
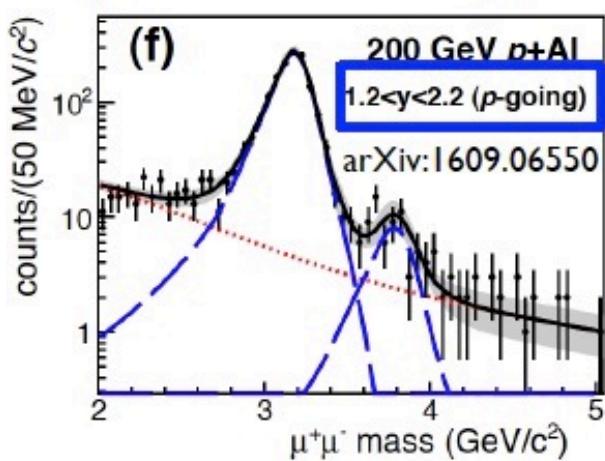
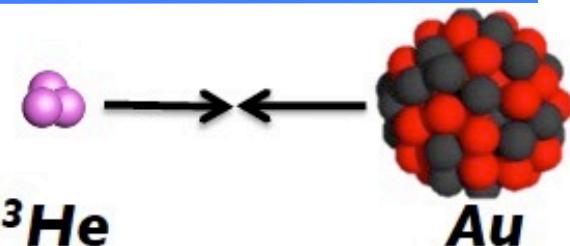
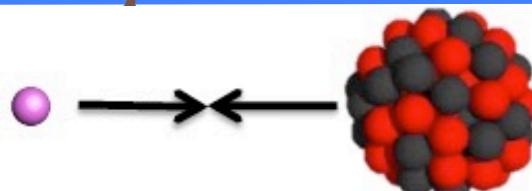
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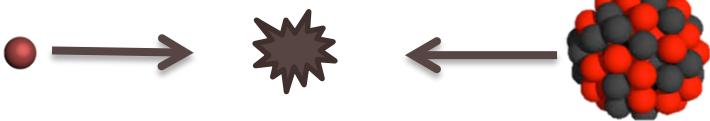
$\Psi(2S)$ at $p+A$ collisions



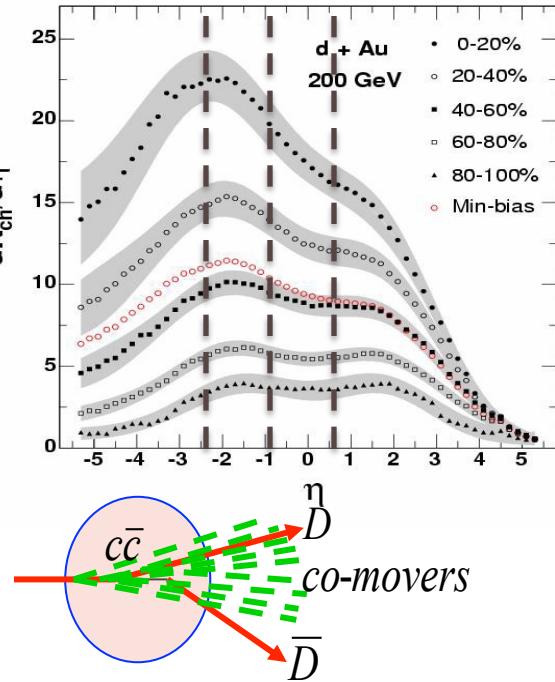
$\Psi(2S)$ at $p+A$ collisions



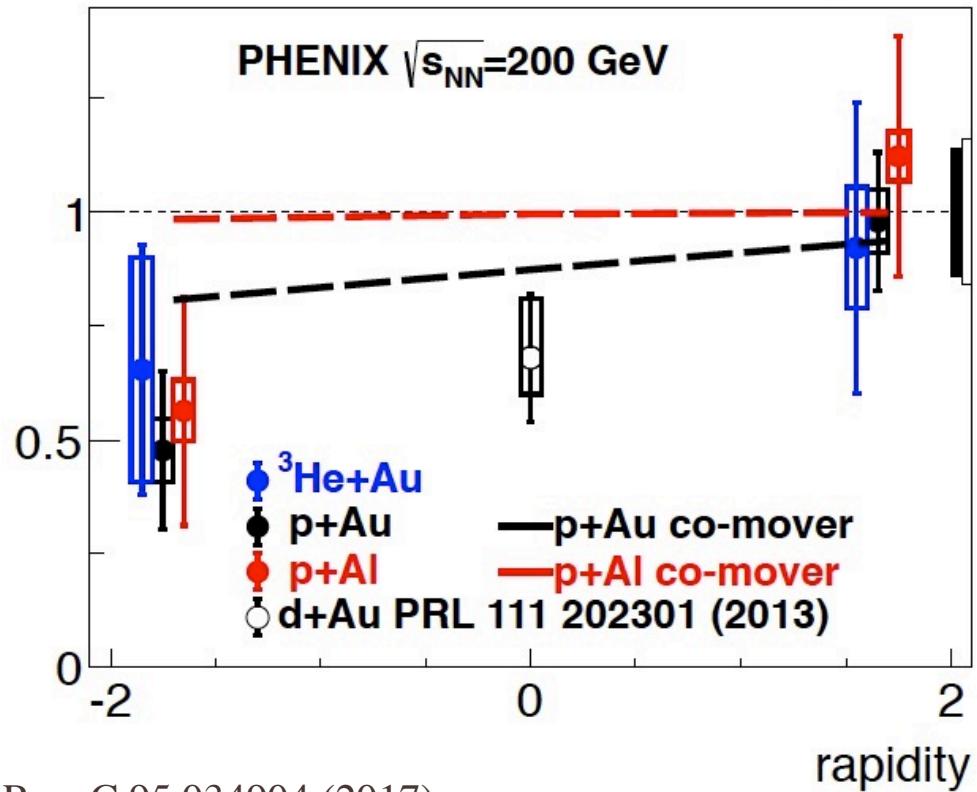
$\Psi(2S)$, easily broken up



Phys. Rev. C 72, 031901 (2005)



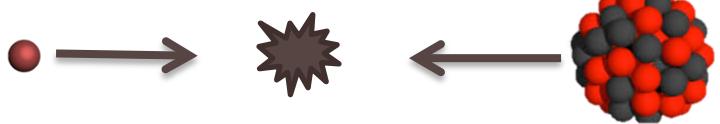
$$\left[\frac{\sigma_{\psi(2s)}}{\sigma_{\psi(1s)}} \right]_{p/{}^3\text{He}+A}$$



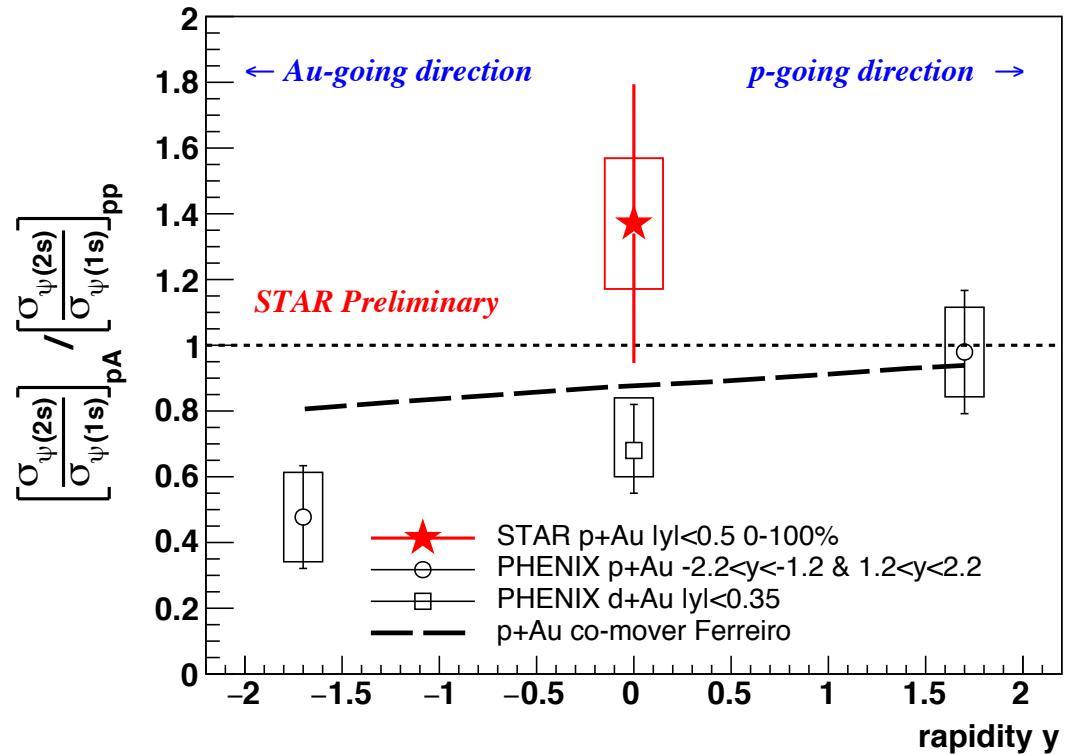
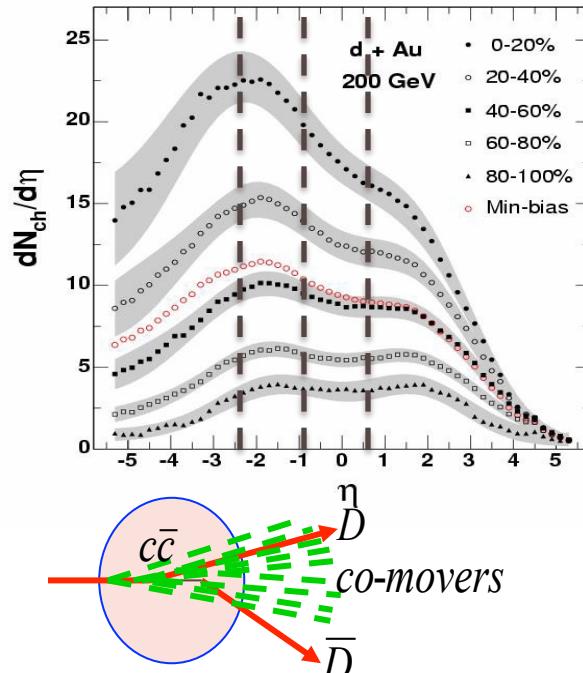
Phys. Rev. C 95.034904 (2017)

Qualitatively agrees with the co-mover dissociation model.

$\Psi(2S)$, easily broken up

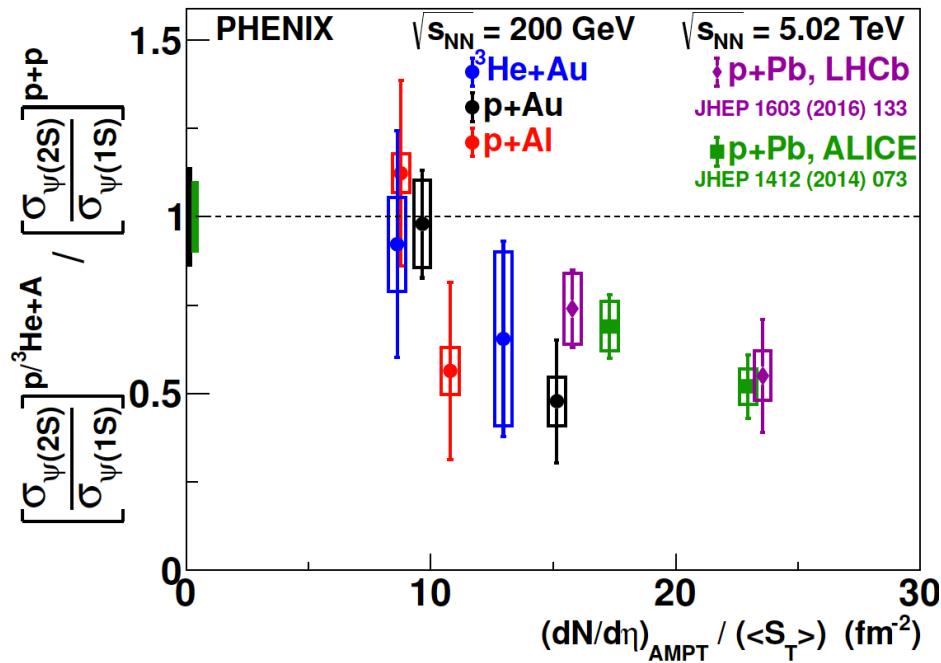
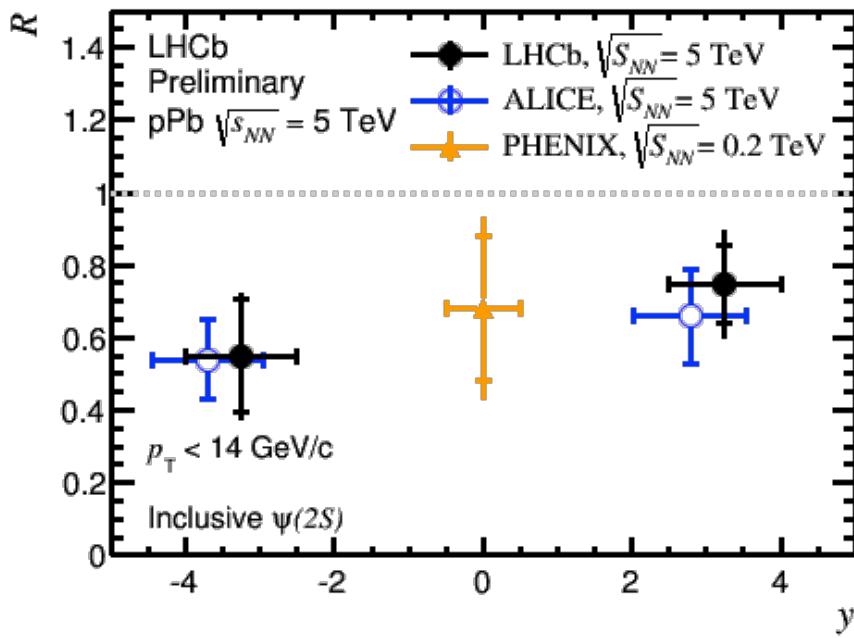


Phys. Rev. C 72, 031901 (2005)



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Comparison to LHC

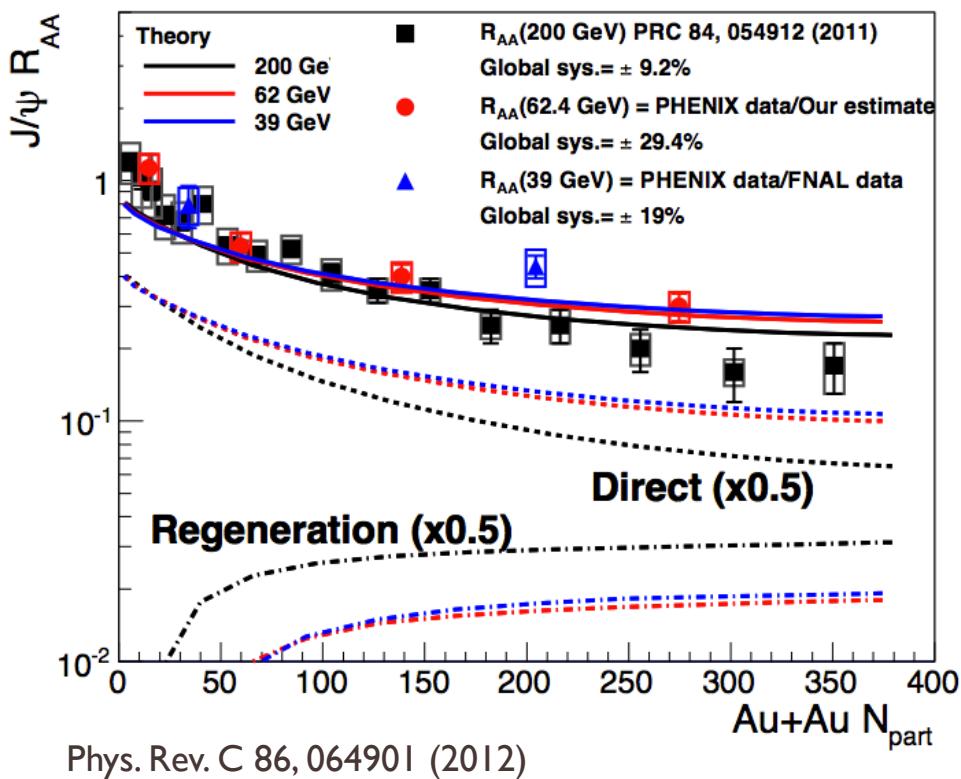


**Similar relative suppression of $\psi(2S)$ at backward rapidity,
but larger relative suppression of $\psi(2S)$ at forward rapidity at LHC**

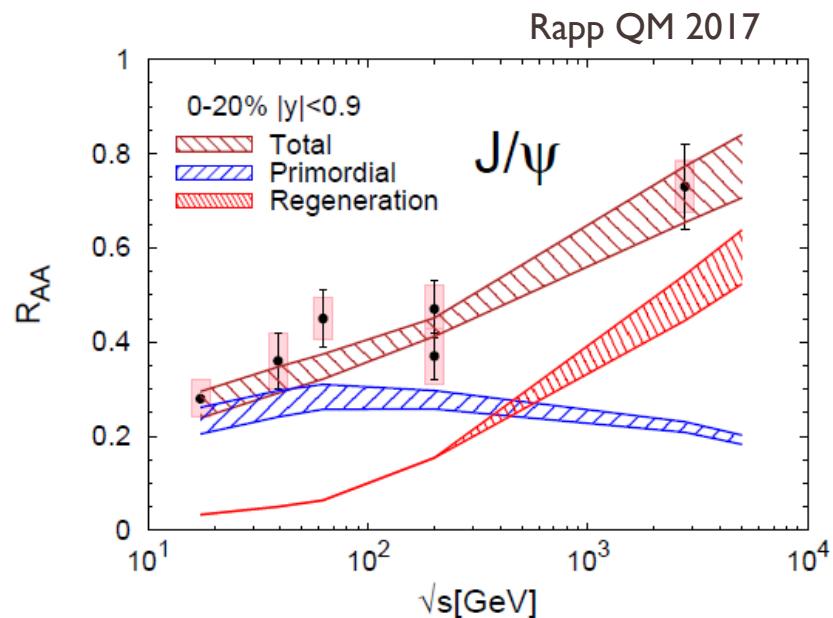
Heavy Ions

Au+Au collisions

**similar suppression of J/ψ
at forward in Au+Au collisions
at 39, 62, and 200 GeV**

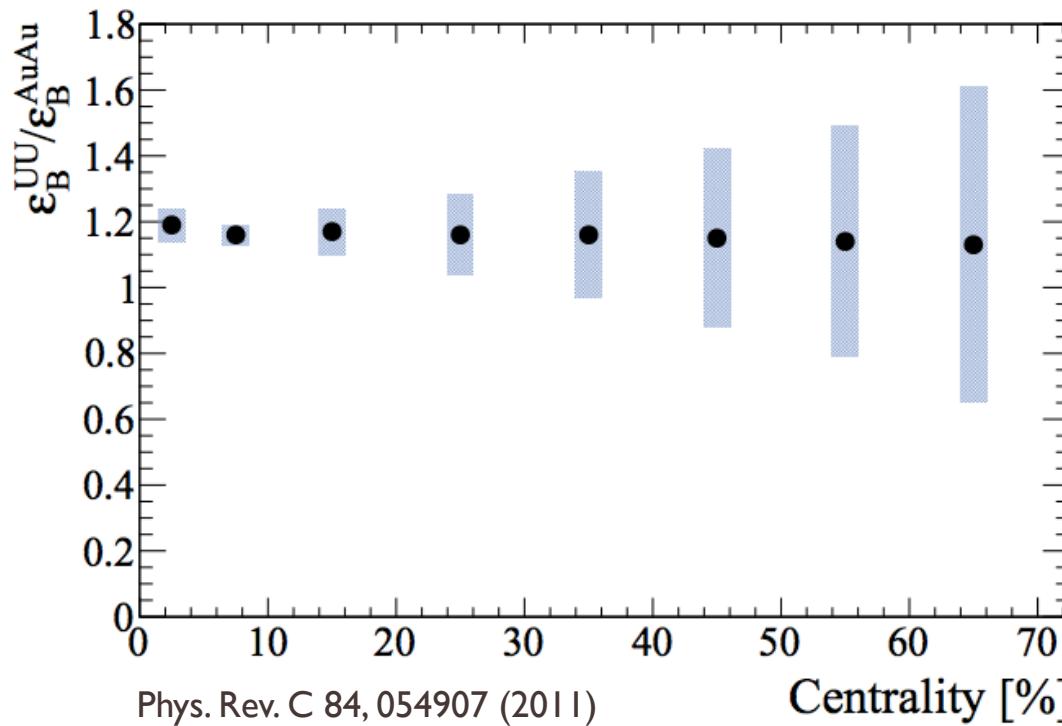


**less suppression at 2.76 TeV
→strong coalescence at LHC**



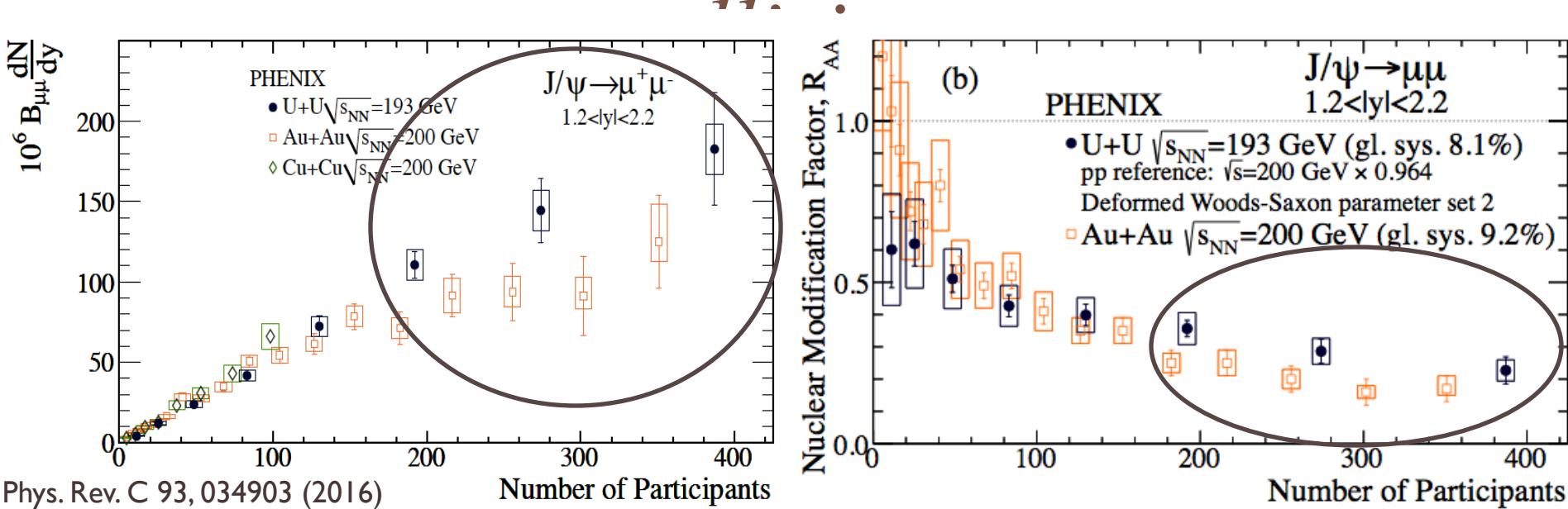
J/ψ production in U+U collisions

- ❖ U+U collisions provide highest density of matters at RHIC
 - ~20% higher energy density than Au+Au collisions
→ expect **stronger color screening**
 - ~25% larger binary collisions (N_{coll})
→ expect **more coalescence**



Phys. Rev. C 84, 054907 (2011)

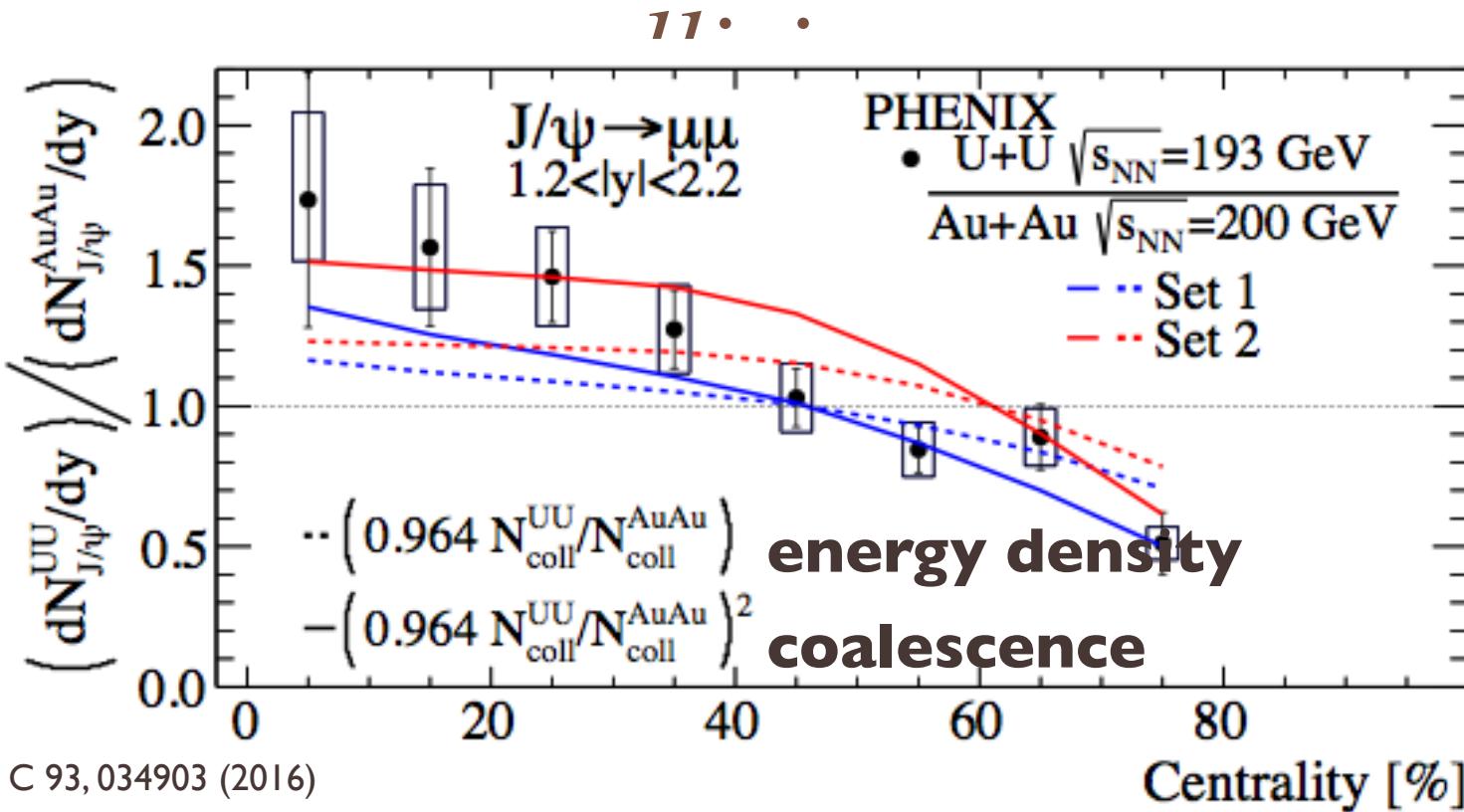
J/ψ measurements in U+U



**more J/ψ production (less suppression)
in central U+U collisions than central Au+Au collisions**

coalescence becomes important in central U+U collisions

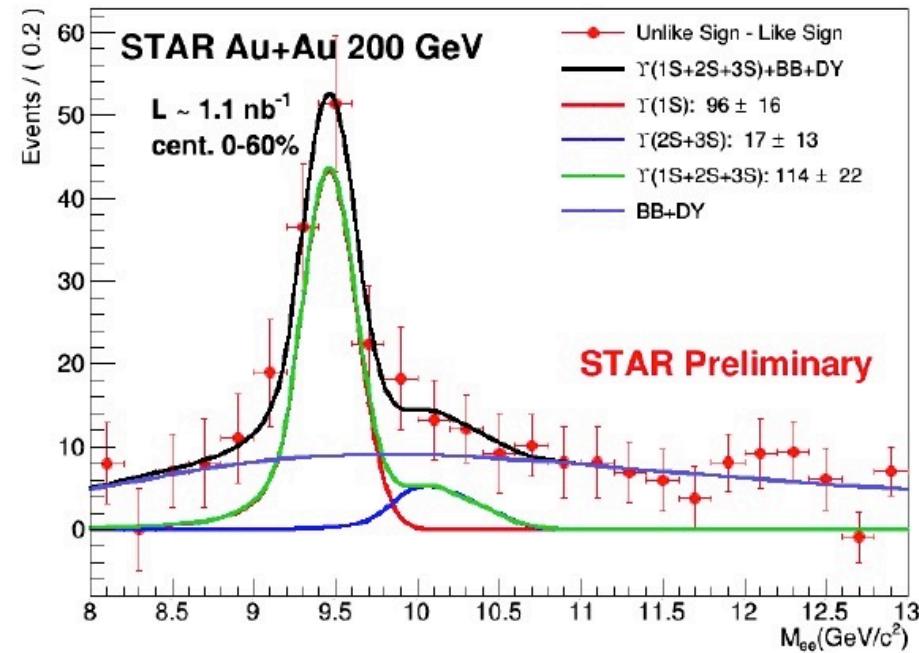
J/ψ measurements in U+U



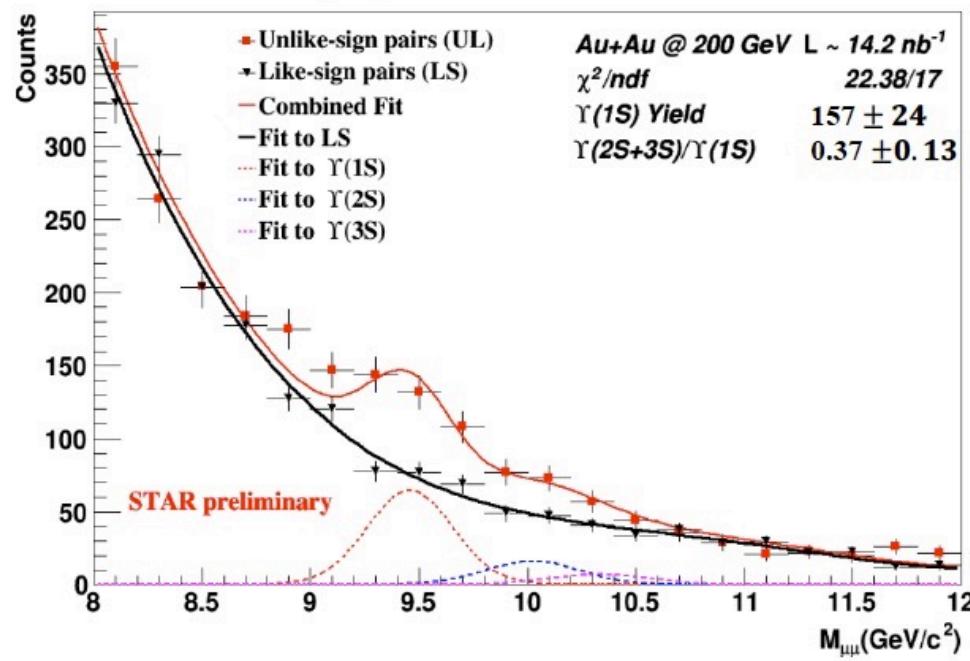
The J/ψ yield ratio between $U+U$ and $Au+Au$ shows a slight preference for N_{coll}^2 scaling in central collisions

Upsilon production in Au+Au

$\Upsilon \rightarrow e^+e^-$ in 2011 Au+Au



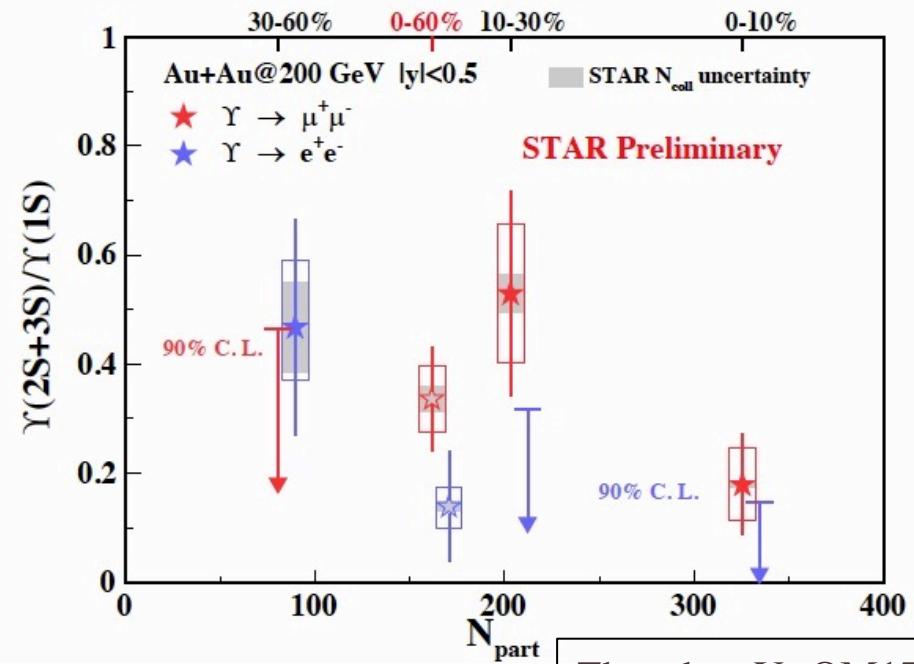
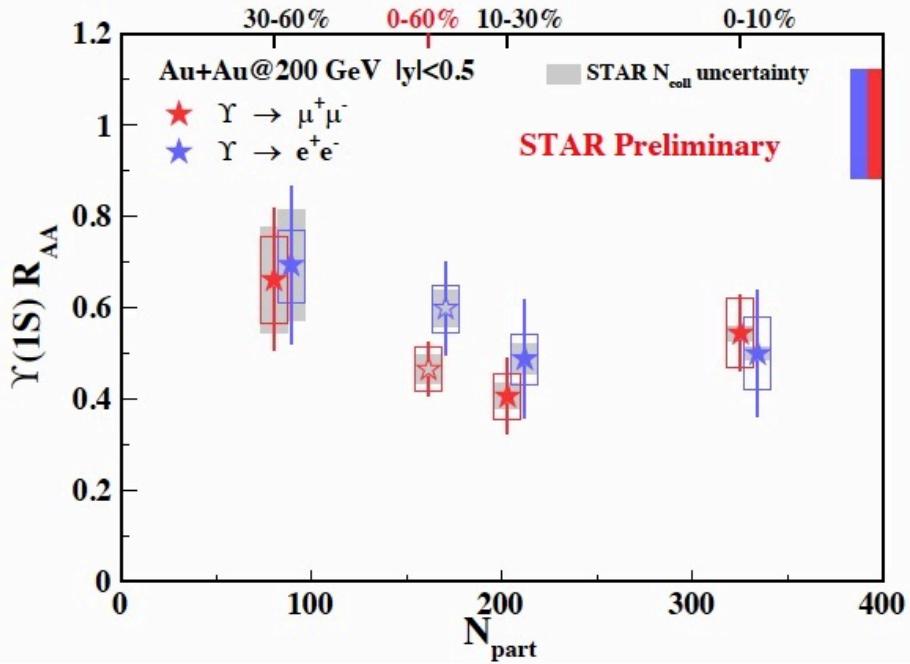
$\Upsilon \rightarrow \mu^+\mu^-$ in 2014 Au+Au



Zhaochen Ye QM17

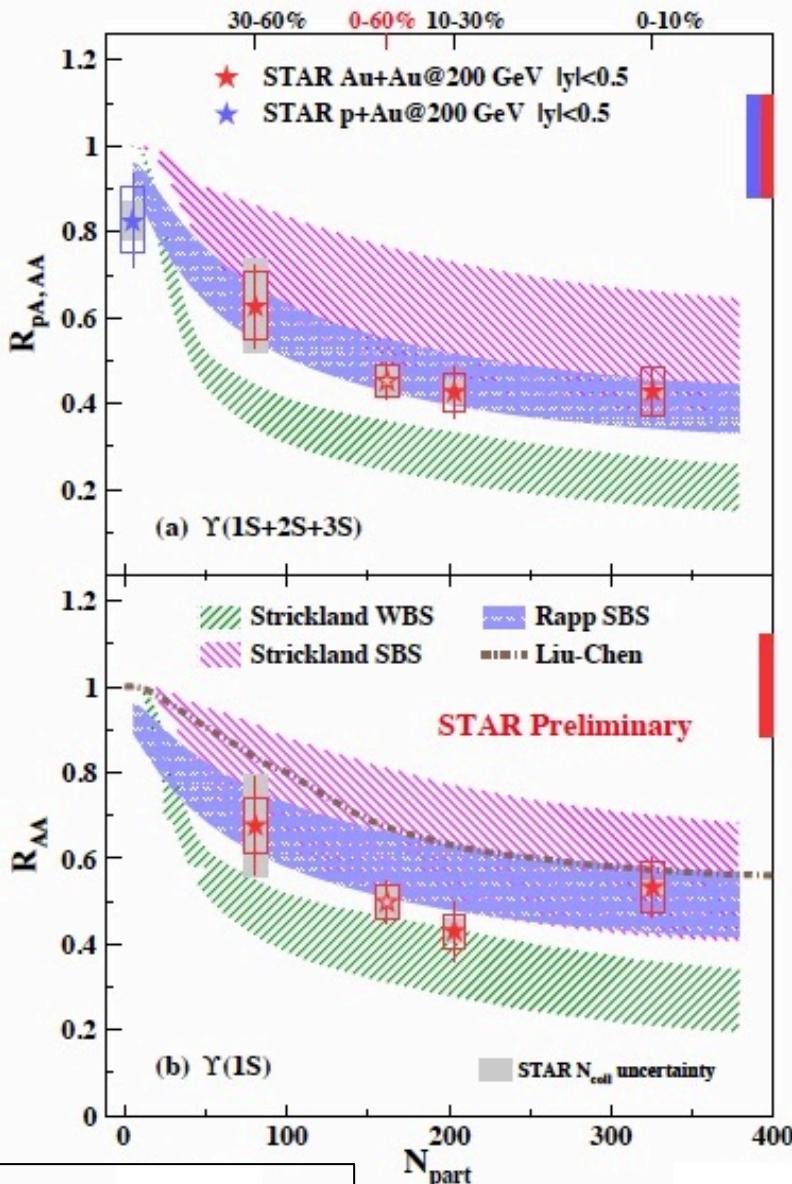
Recent STAR measurements in dielectron and dimuon channels.

Upsilon suppression



- ❖ Consistent between dielectron and dimuon channels.
- ❖ $\Upsilon(2S+3S)$ is more suppressed than $\Upsilon(1S)$: Sequential melting

Model comparison



$\Upsilon(1S+2S+3S)$ and $\Upsilon(1S)$:

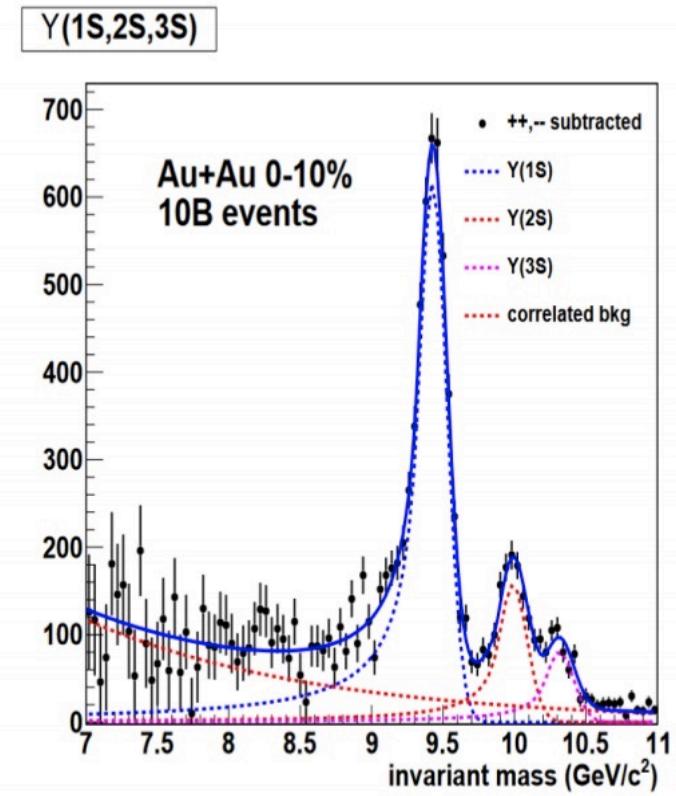
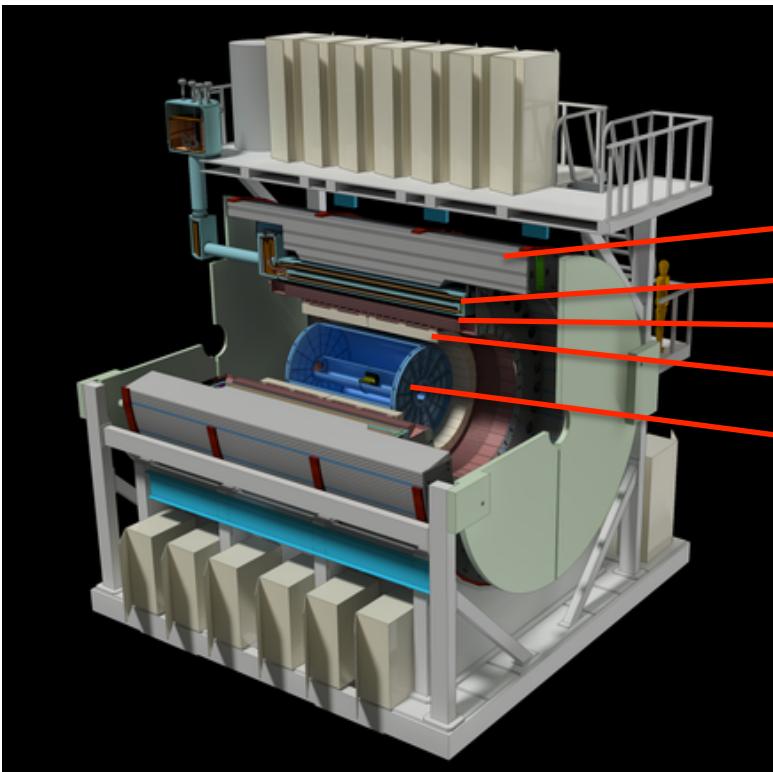
- Indication of more suppression towards more central collisions.

Models:

- Strickland: Expanding fire ball + Feed down
 - WBS: free energy as heavy quark potential
 - SBS: internal energy as heavy quark potential
- Rapp: nPDFs + Absorption cross-section (SBS)

Future of quarkonia at sPHENIX

arXiv:1207.6378



A dedicated jet detector

Design goals:
Mass resolution $< 100\text{MeV}/c^2$
Good e/pi separation

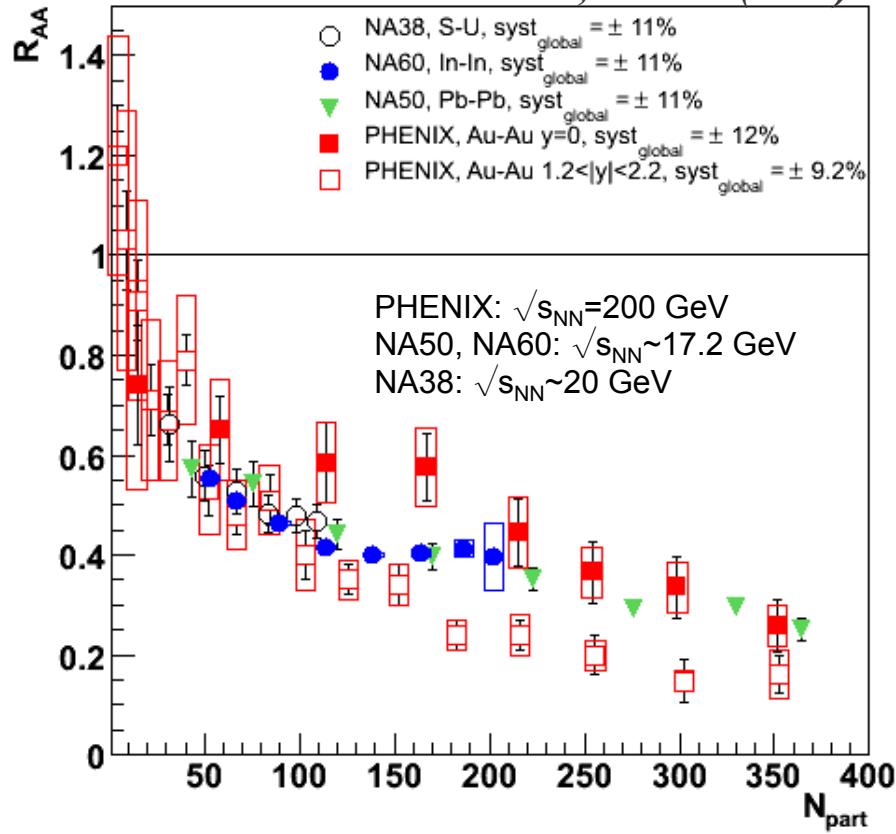
Summary

- ❖ Many mechanisms beyond color screening can contribute to quarkonia suppression.
- ❖ Some of these effects can be disentangled by measuring how they depend as a function of collision energy, momentum, rapidity etc.
- ❖ $\psi(2S)$ measurements at small system:
 - Larger suppression than J/ψ at mid and backward rapidity
→break-up due to co-mover? color screening?
- ❖ J/ψ measurements at U+U collisions:
 - Less suppression in central U+U collisions than central Au+Au collisions.
→coalescence becomes important in central U+U collisions
- ❖ Υ in Au+Au collisions:
 - $\Upsilon(2S+3S)$ is more suppressed than $\Upsilon(1S)$: Sequential melting
 - SBS calculation agrees with data well.

❖ BACK-UPS

$J/\psi R_{AA}$ in $A+A$ collisions

PRC 84, 054912 (2011)



An overview of RAA measurements from 17-200GeV

A admixture of hot and cold nuclear effects which depends strongly on energy and rapidity.

NOT very instructive about the energy dependence pattern

Absorption energy dependence

- Usual parameterisation:
(Glauber model)

$$S_{\text{abs}} = \exp(-\rho \sigma_{\text{abs}} L)$$

break-up cross section

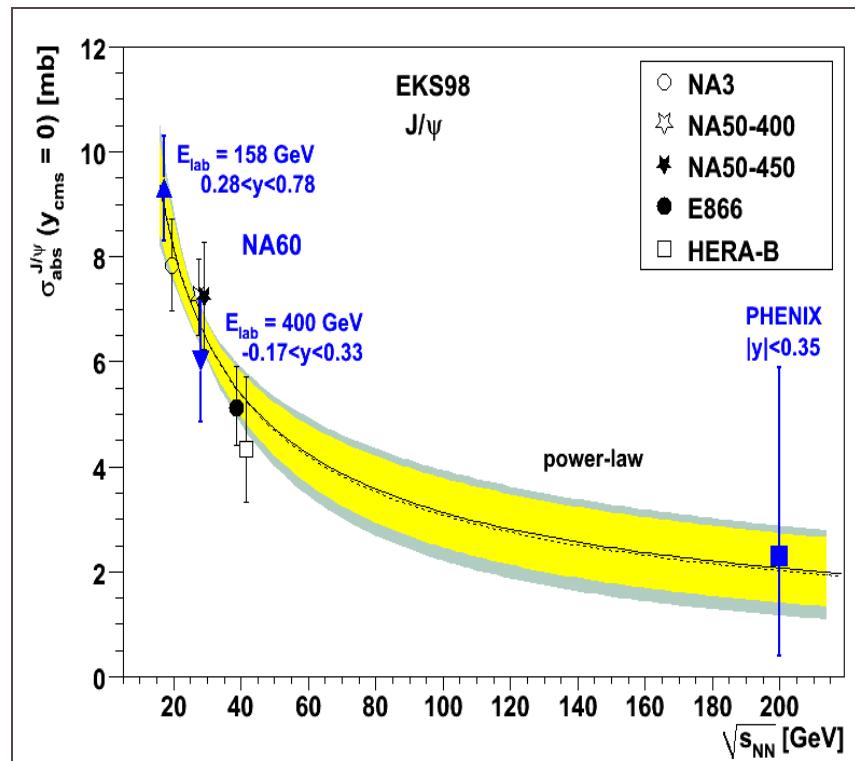
Energy dependence

- **At low energy:** the heavy system undergoes successive interactions with nucleons in its path and has to survive all of them => **Strong nuclear absorption**
- **At high energy:** the coherence length is large and the projectile interacts with the nucleus as a whole => **Smaller nuclear absorption**

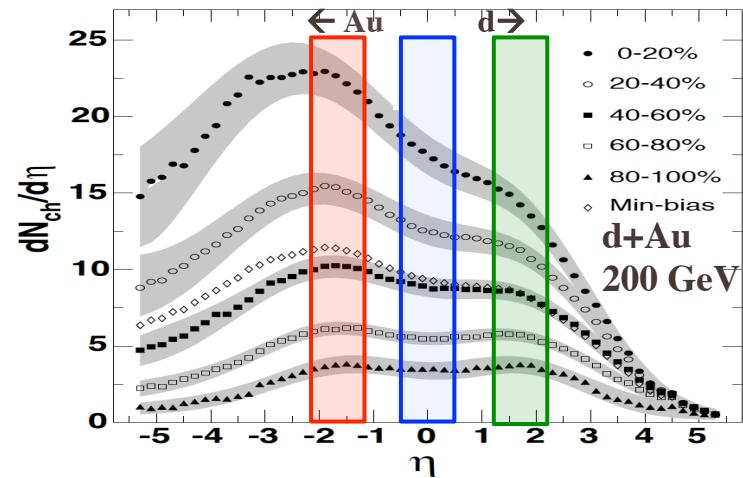
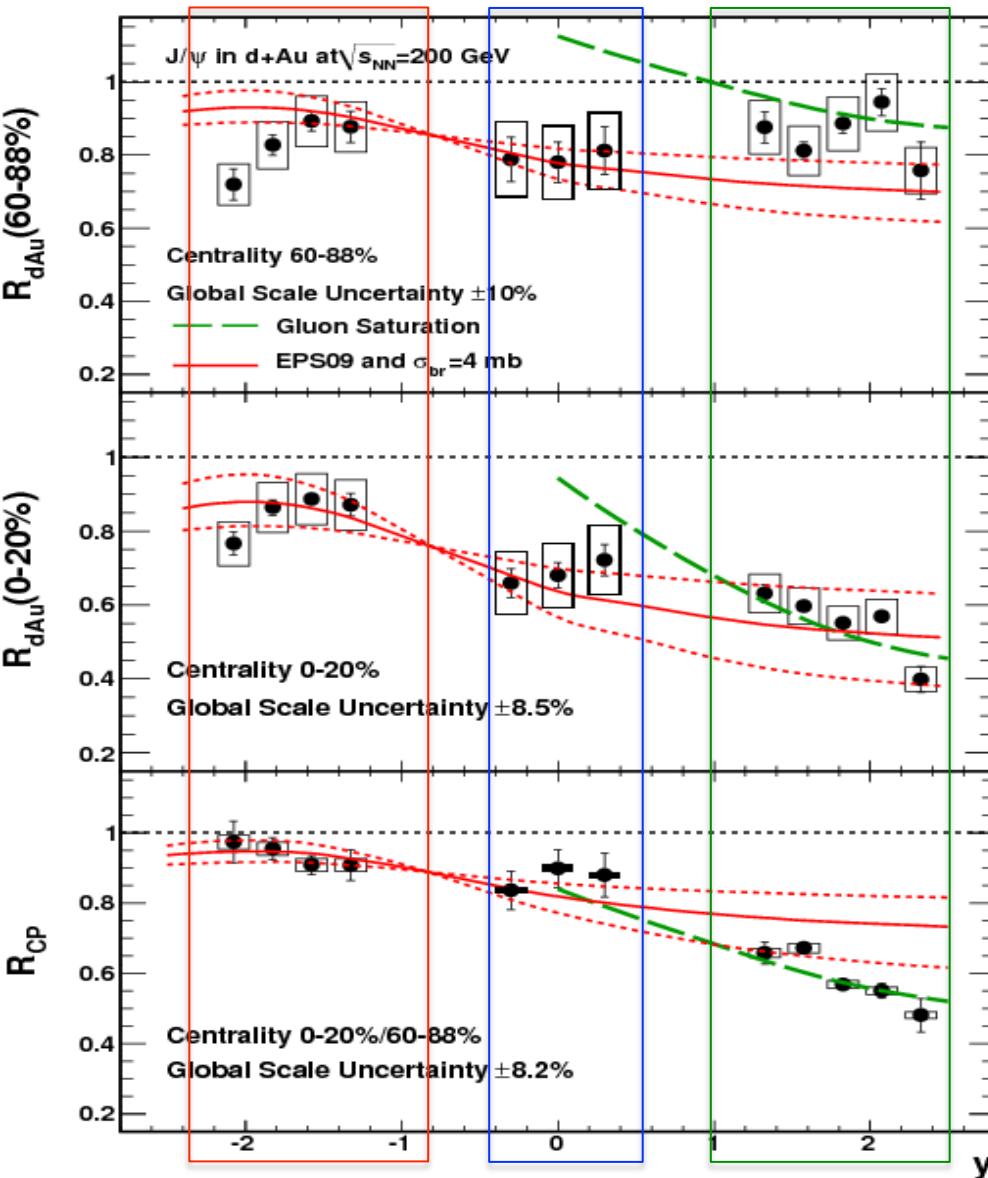
A systematic analysis at $y \sim 0$ using EKS98 + σ_{abs} showed a clear **collision energy dependence** of

σ_{abs} .

JHEP 0902:014 (2009)



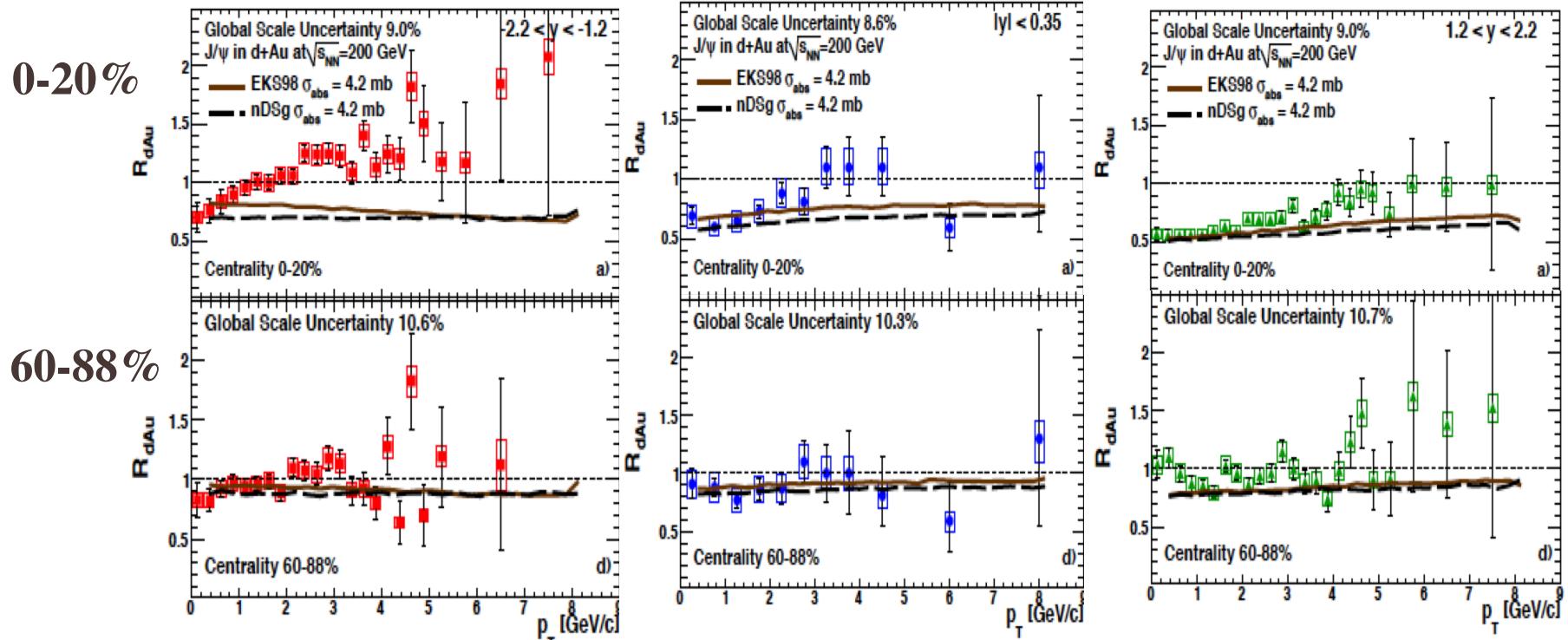
J/ψ suppression in $d+Au$



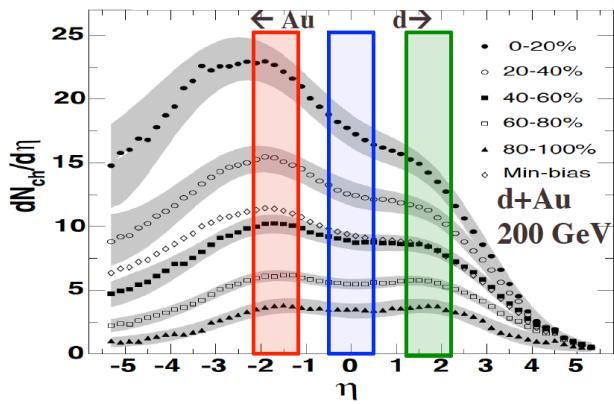
- (Solid Red curves) A reasonable agreement with EPS09 nPDF + $\sigma_{br} = 4$ mb for central collisions but not peripheral.
- (Dashed green line) CGC calculations. (Nucl. Phys. A 770(2006) 40)

Nuclear PDF is nuclear thickness dependent.

$J/\psi R_{dAu}$ vs p_T (centrality bins)



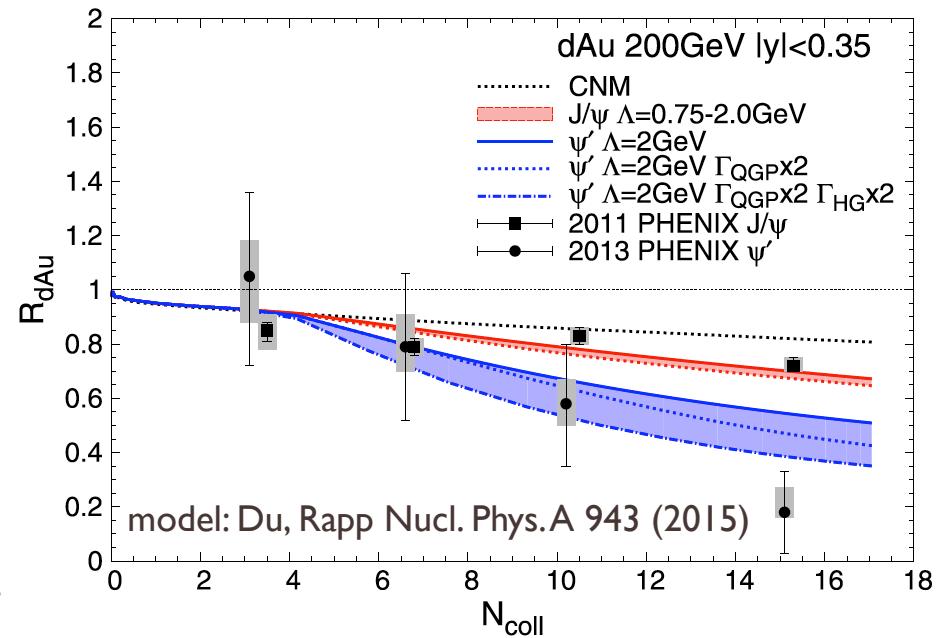
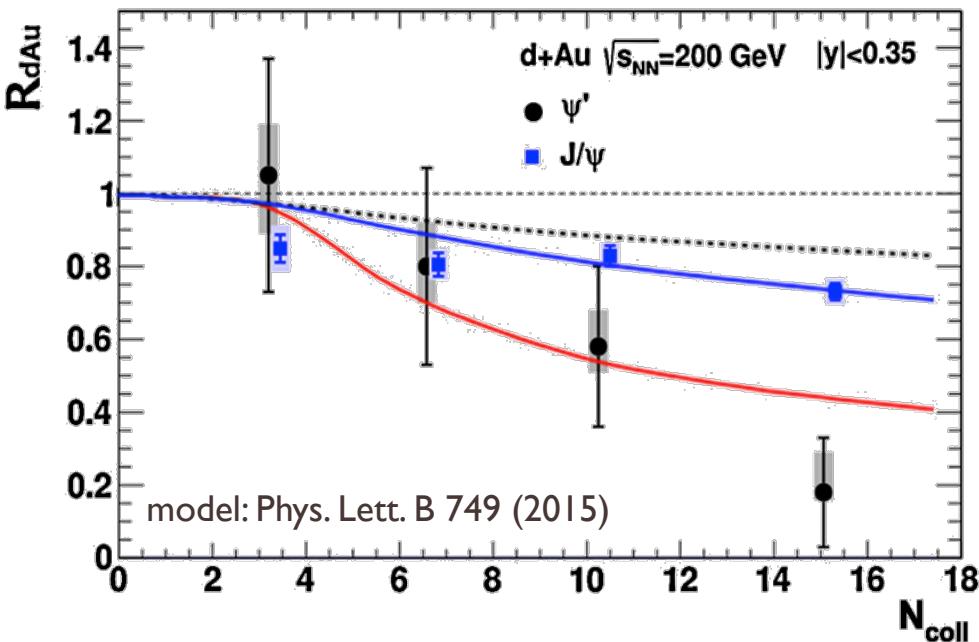
Stronger modification in central. $R_{dAu} \sim 1$ for peripheral collisions within uncertainties.



Calculations from Ferrerio et al. with two different PDFs shows a flat p_T dependence (without Cronin). Strong disagree in central collisions.

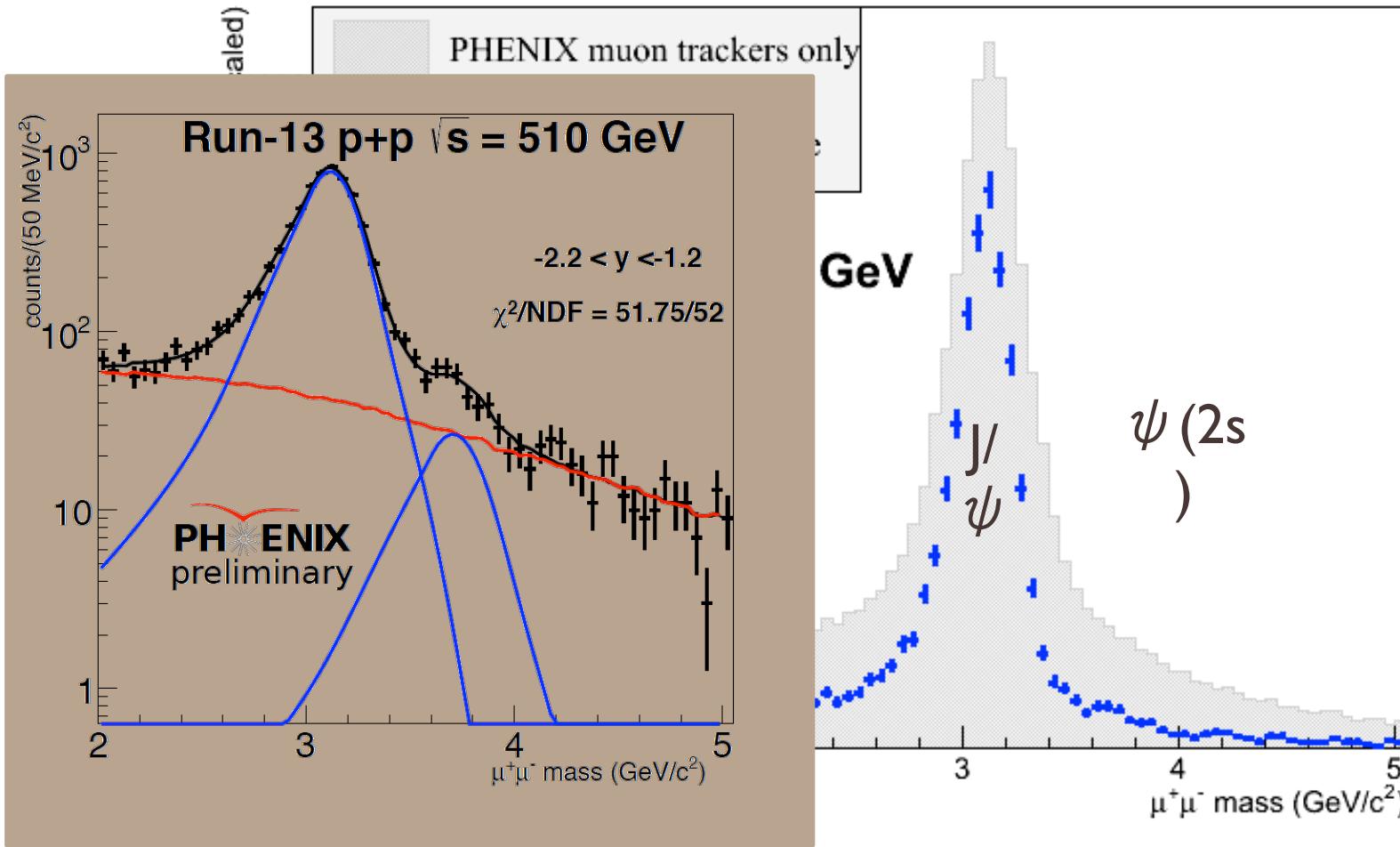
Comparison with models

Nuclear modification factors of J/ψ and $\psi(2S)$ in d+Au collisions at mid-rapidity

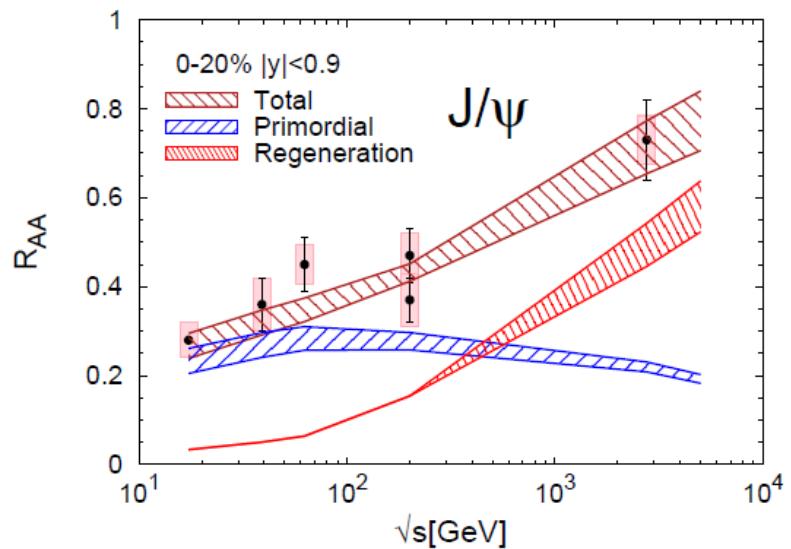


Model including **interaction with co-moving particles** reasonably well describes the suppression of J/ψ and $\psi(2S)$ in d+Au collisions

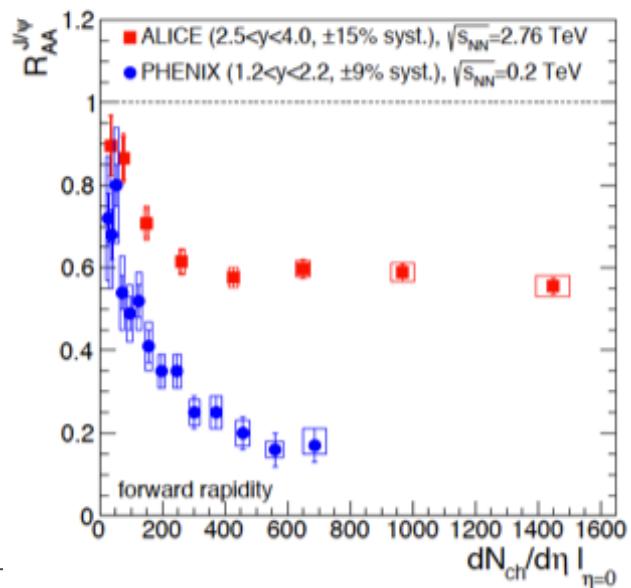
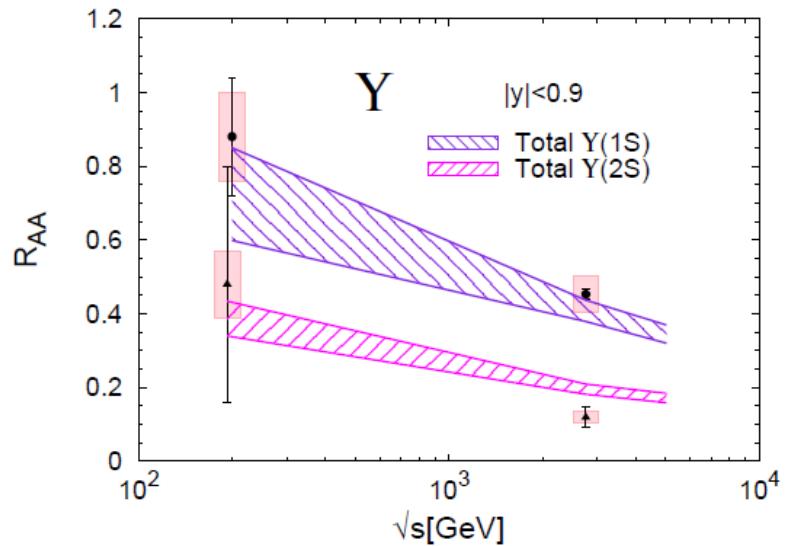
Model considering **QGP formation in central d+Au collisions** and evolution to a hadronic gas state also show an agreement with the data



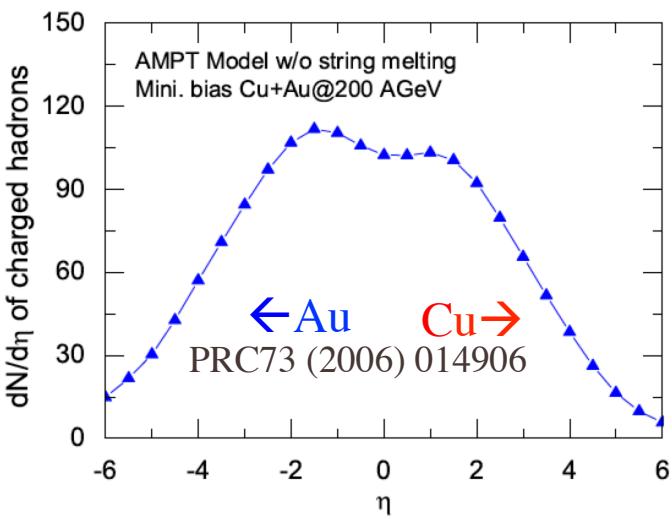
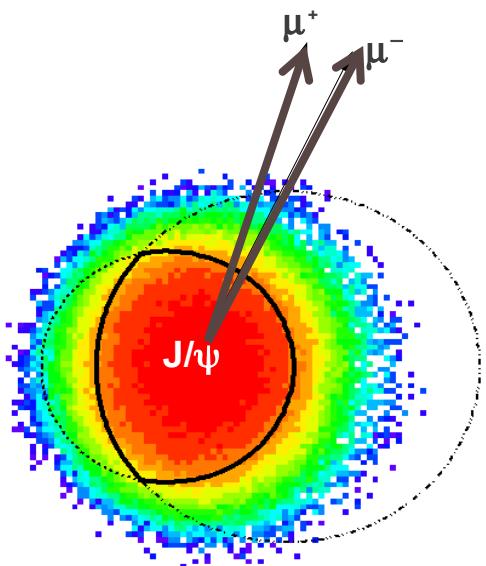
Charmonium



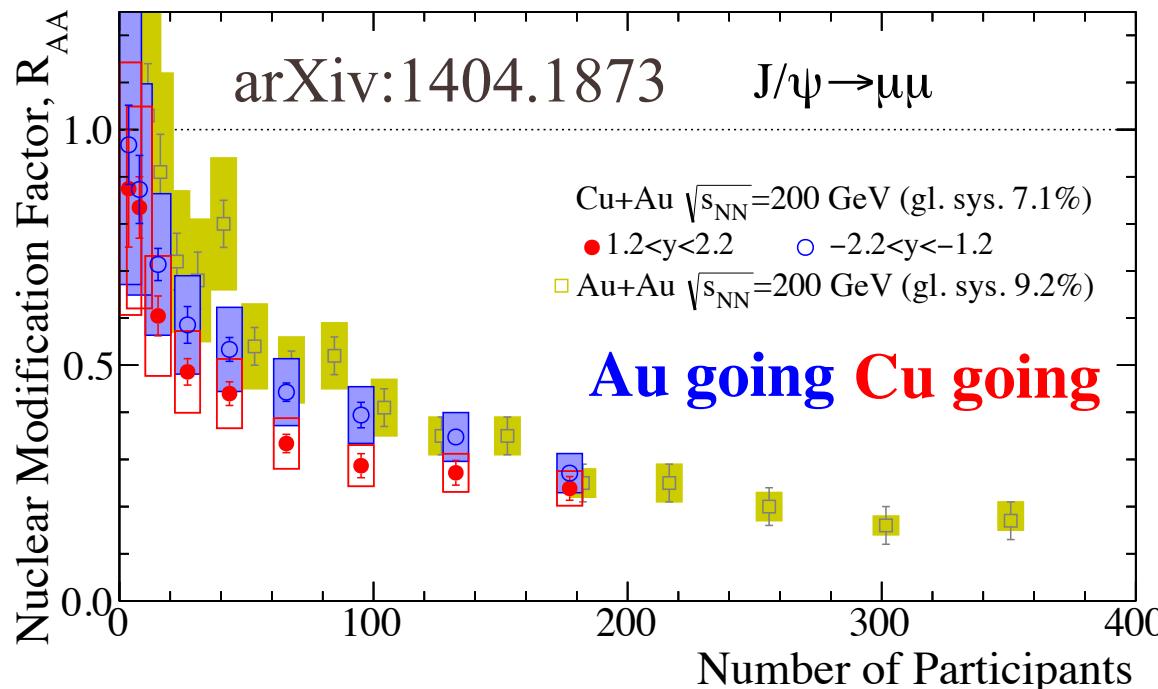
Bottomonium



Cu+Au (new Geometry)



Asymmetric nuclear effects

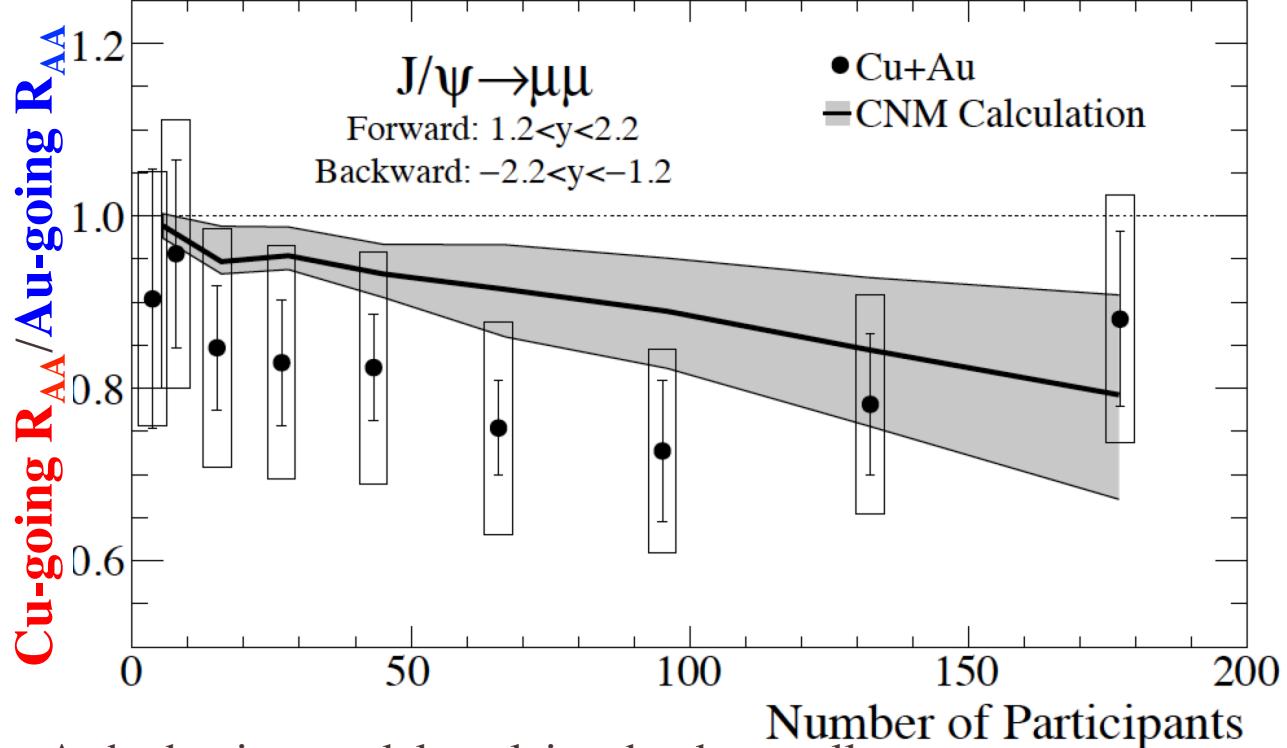


Higher suppression in region of lower particle density. Similar to d+Au collisions.

Hot nuclear matter effect would have effected the other way.

Cu-going-side/Au-going-side

arXiv:1404.1873



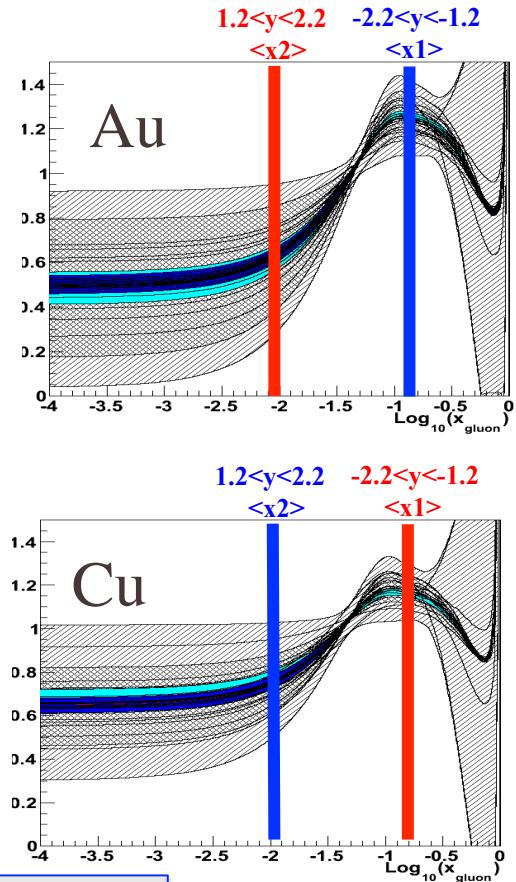
A shadowing model explains the data well

Au-going direction :

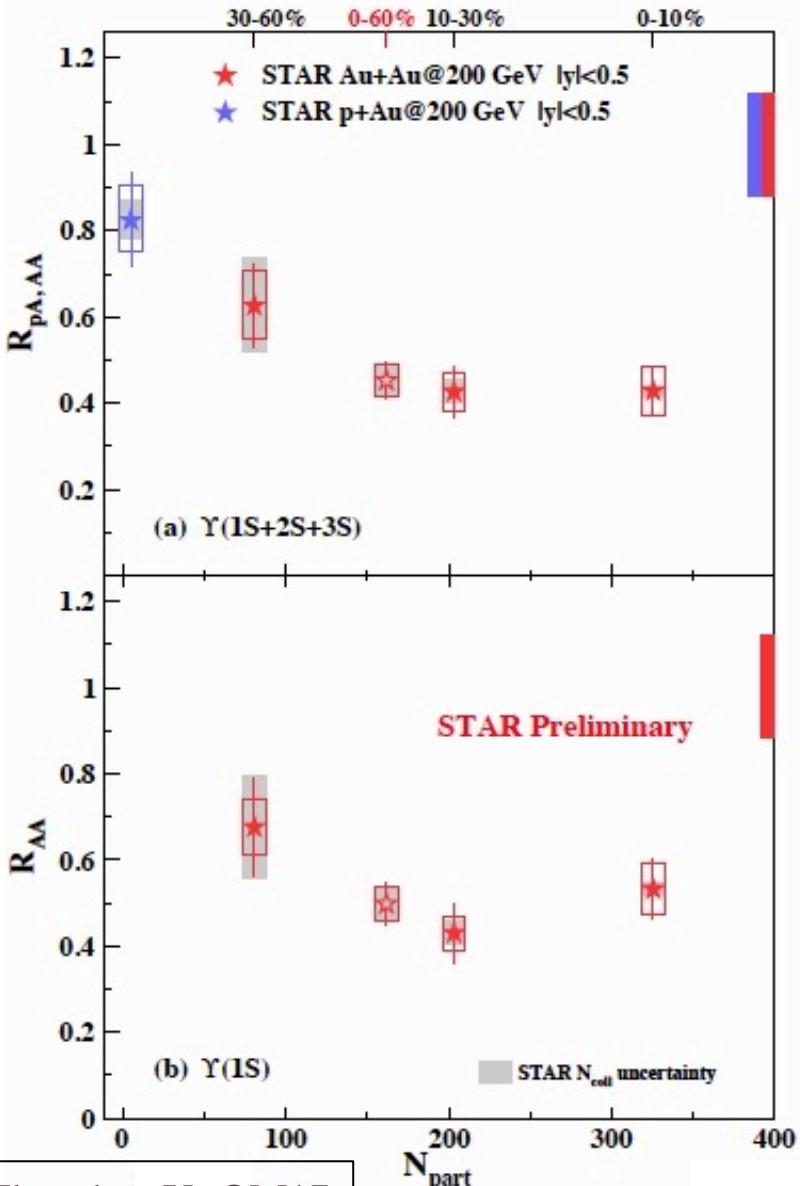
low-x partons in Cu nucleus * high-x partons in Au nucleus

Cu-going direction:

low-x partons in Au nucleus * high-x partons in the Cu nucleus



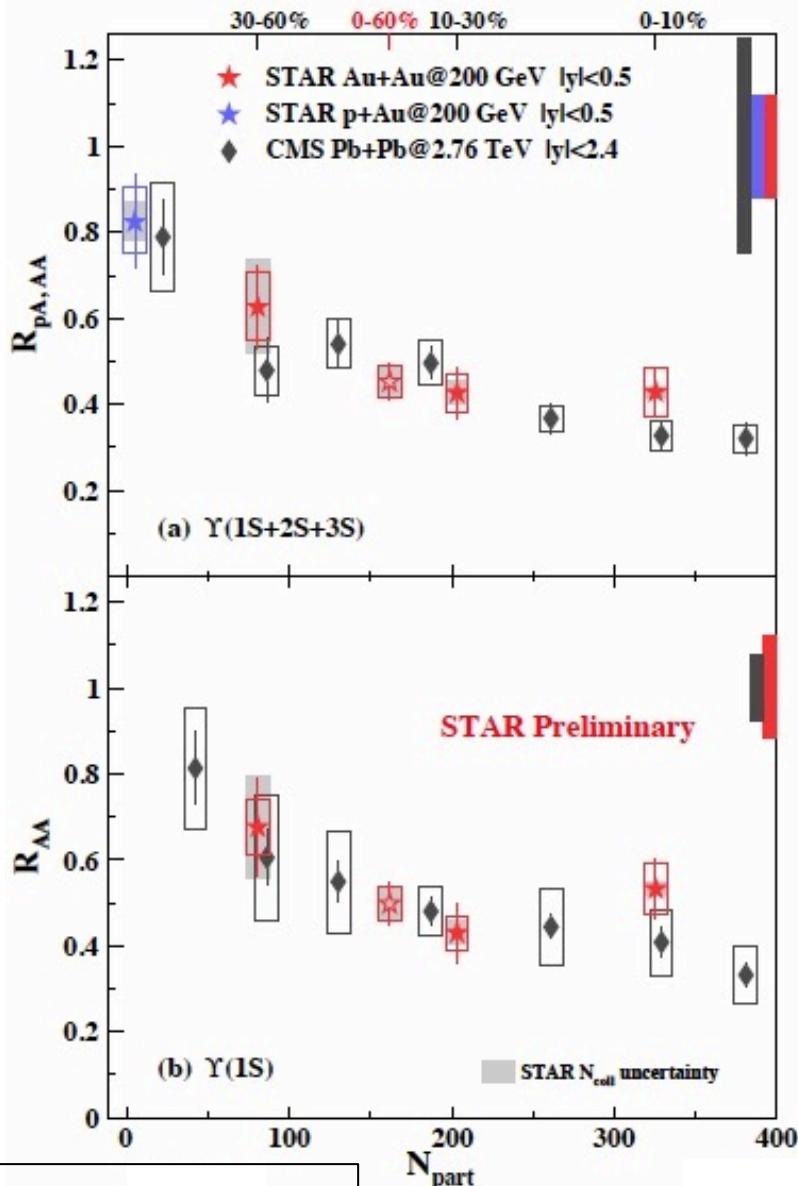
Y suppression in Au+Au collisions



$\Upsilon(1S+2S+3S)$ and $\Upsilon(1S)$:

- Indication of more suppression towards more central collisions.

Comparison to LHC



$\Upsilon(1S+2S+3S)$ and $\Upsilon(1S)$:

- Indication of more suppression towards more central collisions.
- Similar suppression at RHIC and LHC.

STAR $\Psi(2S)$ measurement

